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LINKING DEVELOPMENTAL WORKING MEMORY
AND EARLY ACADEMIC SKILLS

A Dissertation

Submitted to the School of Education

Duquesne University

In partial fulfillment of the requirements for
the degree of Doctor of Philosophy

By

Janice E. Decker

May 2011

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Janice E. Decker

2011

DUQUESNE UNIVERSITY
SCHOOL OF EDUCATION
Department of Counseling, Psychology, and Special Education

Dissertation

Submitted in partial fulfillment of the requirements
for the degree
Doctor of Philosophy (Ph.D.)

School Psychology Doctoral Program

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February 14, 2011

**LINKING DEVELOPMENTAL WORKING MEMORY
AND EARLY ACADEMIC SKILLS**

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ABSTRACT

LINKING DEVELOPMENTAL WORKING MEMORY

AND EARLY ACADEMIC SKILLS

By

Janice E. Decker

May 2011

Dissertation supervised by Professor Jeffrey Miller, Ph.D., ABPP

Brain-based initiatives and school readiness mandates in education have prompted researchers to examine the biological mechanisms associated with learning in the hope that understanding empirical evidence can maximize learning potential. Current research has examined working memory skills in relationship to early learning. The function of working memory is best examined in the context of childhood developmental theory using the framework of Baddeley and Hitch's model. Understanding developmental working memory components in regards to early reading and math skill acquisition is important to designing appropriate interventions. This study represents an initial effort to analyze kindergarten developmental screening results in conjunction with early academic reading and math probes, and may aid in identifying patterns on strengths and weaknesses for future educational planning and intervention. Such information may lead

to further development of more specific working memory screening aspects in the kindergarten screening process. One hundred ninety-six kindergarten students ages 4 to 6 from two elementary schools were included in the study sample. Results indicated the correlation of phonemic segmentation skills in kindergarten and short-term auditory memory performance on a kindergarten screening measure is predictable. Despite the effect of socioeconomic status, lower short-term auditory memory performance was associated with lower letter naming fluency, letter sound fluency and phoneme segmentation skills throughout the kindergarten year. The relationship of early numeracy skills in kindergarten and short-term visual memory performance on a kindergarten screening measure is predictable. Although preschool experience has an effect on early numeracy skills, short-term visual memory performance was associated with lower number identification, quantity discrimination and missing number achievement. Additional results indicated that kindergarten screening measures of nonverbal and verbal skills, including short-term auditory and visual memory, successfully predict Response to Intervention and Instruction Tier placement in the Fall semester. These findings suggest that interventions should be implemented as soon as a child enters school in order to maximize progress. Research indicates there is evidence linking developmental working memory skills to early learning but more empirical evidence is needed to support the application of neuroscience principles to school readiness practices, specifically in regards to screening assessments, working memory and early academic performance.

DEDICATION

This dissertation is dedicated in memory of my brothers, Chip and Todd, and in honor of my parents, Charles and Cecilia Marhefka Decker. My brothers were my first students, helping me to discover the joy of sharing how to form a number or read a story. In memory of Chip, I strive to carry his generous spirit and open heart in all I do. In memory of Todd, I hope to be strong and brave.

Mom and Dad, you were my first teachers. You gave me a love of learning and a life-long commitment to the importance of education, as well as provided unending encouragement and support. You taught me to dream, create and persevere. Your grace and faith throughout the most difficult times inspire me. I am grateful and honored to be your daughter.

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Acknowledgement must be given to the memory of two dear Sisters of Charity and professors at Seton Hill University. Sr. Miriam David Volker, Professor of Piano and Music Theory, was instrumental in encouraging my love of music and learning. Her wisdom and quiet strength is with me always. I would also like to acknowledge the influence of Sr. Maurice McManama, Professor of Psychology. She shaped many of my perceptions of the importance of early intervention, special education and school psychology.

Much gratitude is extended to my friends throughout the years. You sustain, encourage and bring laughter to my life. I would also like to thank the administration, staff, students and parents of Hempfield Area School District for their support and confidence. And finally, I would like to thank all my teachers throughout the years who have so positively influenced my life and the lives of countless children. To teach is to truly touch the future.

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CHAPTER 1

INTRODUCTION

After reading an evaluation on a student, a kindergarten teacher asked what could be done to help a child with working memory deficits to learn more efficiently. This question is the foundation of brain-based research in current education circles. Working memory refers to the cognitive ability to take in, hold and manipulate information over short periods of time (Alloway, 2006; Gathercole, 2009). Older constructs of working memory (then called short-term memory) refer to it as the “workspace” or “blackboard” of the brain (Atkinson and Shiffrin, 1971; Miyake & Shah, 1999). Robert Logie (1999) updates his description of working memory as the desktop of the brain. Easy access, organization and manipulation of frequently used icons are the hallmarks of a well working computer desktop. Application of these ideas to the abstract concept of working memory aids in making the idea more tangible for educators to maximize working memory in the learning process for children.

Significance of Working Memory Research in Education

Throughout the past three decades in education research, a field has emerged known as brain-based education. This discipline uses research in neuroscience on how the brain functions to increase understanding of learning and apply this knowledge to the classroom (Jensen, 2008; Madrazo & Motz, 2005). Brain-based initiatives in education have prompted researchers to examine the biological mechanisms associated with learning with the hope that understanding and empirical evidence can maximize learning potential (Alloway, 2006; Gathercole & Alloway, 2006).

A current topic of brain-based research is the correlation of working memory with learning. Working memory is vital because it provides a mental “workspace” where information can be held while engaged in learning activities. Research findings point towards a close relationship between school achievement and working memory skills (Alloway, Gathercole, Adams, Willis & Lamont, 2005; Alloway, Gathercole, Willis, & Adams, 2004). Working memory capacity is the central information processing mechanism underlying individual differences in fluid intelligence. Horn and Cattell first defined fluid intelligence as to the ability to encode short term memories, as well as solve novel problems and to reason quickly. Measures of fluid intelligence are more sensitive indicators of brain malfunction (Engle, Kane, & Tuholski, 1999; Horn, 1968). Thus, deficits in working memory can contribute to learning disabilities, which are associated with weaknesses in domain specific processes involved in creating and maintaining phonological representations, as well as domain general working memory capacity (Hambrick, Wilhelm, Engle, 2001; Engle, Tuholski, Laughlin & Conway, 1999). There is also a significant relationship between working memory and learning. Gathercole and Adams (1993) demonstrated that scores on word and nonword repetition tasks are linked to vocabulary knowledge. Understanding how memory works and functions in the learning process is important in addressing learning needs and designing interventions from the time a child enters school (Gathercole & Alloway, 2008).

In addition, school readiness mandates (No Child left Behind Act of 2001; National Education Goals Panel; Goals 2000: Educate America Act) require that children be screened as they enter school in order to provide information about where the child’s developmental path may be off track and to design interventions to address these areas

(Brassard & Boehm, 2007; Mehaffe & McCall, 2002). Blair and colleagues (2007) have focused on application of neuroscience to school readiness. Research indicates there is evidence linking developmental working memory skills to early learning, but more empirical evidence is needed to support this concept.

This study will explore possible links between aspects of working memory development, kindergarten screening results and early academic skill acquisition. Currently, screening data is generally used for decision making regarding full-day kindergarten placement. Additional empirical evidence in this area may lead to consideration of specific kindergarten screening data in planning interventions as a child enters school and to target specific working memory deficits before a child is referred for reading and math learning difficulties.

Working Memory Theoretical Basis

Understanding the theories and neurobiological nature of memory formation and working memory is fundamental to empirical research. Because working memory is a construct involving attention and short-term memory encoding, and long-term memory retrieval, researchers have proposed various models to explain how this process functions in learning (Baddeley, 2003; Pickering, Gathercole & Lloyd, 2001; Swanson, 2008; Shah & Miyake, 1999).

There are many models with empirical evidence, but Baddeley and Hitch's model is the most cited in research studies (Alloway, 2006; Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998; Baddeley & Hitch, 2000; Baddeley & Logie, 1999; Gathercole, 2008). This model has been particularly useful in the analysis of the neural foundation of working memory (Baldo & Dronkers, 2006).

Baddeley's multi-component construct theorizes that there are two "slave systems", the phonological loop and visual-spatial sketchpad, responsible for short-term encoding and maintenance of information, and a "central executive" responsible for supervision of information integration and coordination of the slave systems. The phonological loop is fractionated into phonological store and an active rehearsal or articulatory control process. The visuospatial sketchpad is fractionated into a passive visual cache and active spatial construct called inner scribe. The central executive is responsible for integrating information and coordinating systems. It holds representations and integrates phonological, visual and spatially encoded information, as well as perceptions not included in the slave systems (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998).

Baddeley added a fourth component, the episodic buffer, to this working memory model. The role of the episodic buffer is to hold representations and integrate phonological, visual and spatially encoded information, as well as perceptions not included in the slave systems such as semantic or musical information (Baddeley, 2003; Baddeley & Logie, 1999). The episodic buffer has been described as a structural alternative to the idea of a long-term memory framework (Ericsson & Delaney, 1999; Towse & Hitch, 2008).

Baddeley's model of working memory could be viewed in the context of the parts of a classroom. Instruction is presented verbally, similarly to the phonological loop function. Such verbal information can be rehearsed (articulatory control) until it is stored and learned (phonological store). Visual information is presented on the blackboard (as objects in the visual cache), with specific information presented in graphs (spatially, in

the inner scribe) representing the visual sketchpad. The teacher, who directs and controls information and attention, can be thought of as the central executive. Finally, notebooks, in which all the presented information is stored for later access, is much like the episodic buffer.

When all these parts work efficiently, learning occurs. However, if verbal information is not rehearsed or visual information is overwhelming, the learning process may be interrupted. If the teacher cannot control attention or coordinate all of the activities, learning may not occur. Finally, when any of these breakdowns happen, the learned information will not be stored in the notebooks. Each of these parts of a classroom can be thought of parts of the working memory system. Each of these parts has been associated with specific brain anatomy through research.

Working memory processes are primarily localized in the dorsolateral prefrontal cortex. Imaging studies indicate working memory demands cause significant increases in dorsolateral prefrontal cortex activity compared to non-working memory tasks (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998).

Phonological loop activity is associated with left-hemisphere activation. Neuroimaging studies indicate the right hemisphere is active in visuospatial working memory, especially in the right occipital and inferior frontal lobes (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998). The central executive, core of the working memory process, is associated with the prefrontal cortex (Baddeley & Logie, 1999). Recent studies have pointed to the left hippocampus, posterior regions and middle temporal lobe as structures associated with the episodic buffer (Rudner, Fransson, Ingvar, Nyberg & Rönnerberg, 2007). The left hippocampus consolidates recent memory to long-

term memory. Thus, the episodic buffer integrates information from a variety of sources across time and space, feeding this information into long-term memory and retrieving it from long-term memory (Baddeley, 2000).

The function of working memory is best understood in the context of childhood developmental theory using the framework of Baddeley and Hitch's model (Gathercole, 1998; Gathercole & Alloway, 2008). More specifically, researchers are investigating possible relationships between young children's specific working memory processes with early academic skills in reading and math (Alloway, Gathercole, Willis & Adams, 2004). Working memory is required when learning because skill acquisition needs short-term memory, interaction with long-term memory, as well as simultaneous storage and processing of information.

In this study, the specific processes of working memory that will be examined in regards to early learning skills are the phonological loop and the visual-spatial sketchpad. As evidenced in the developmental literature, these processes are the foundation of developmental working memory progression in young children, as well as being associated with early academic skills.

Critical Analysis of Relevant Literature

A critical analysis of relevant literature supports the idea that the phonological loop, including the phonological store and articulatory rehearsal process, plays an important role in language acquisition, and early reading skills such as phonemic awareness (Baddeley & Logie, 1999; Roth, Speece & Cooper, 2002; Spear-Swerling, 2007). Phonological short-term memory may influence learning letter-sound correspondences and storage of generated phonological sequences prior to blending and

output during phonological recoding (Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005). Research indicates that the most common cause of difficulties acquiring early word reading skills is weakness in the ability to process the phonological features of language (Baddeley, Gathercole & Papagno, 1998). In addition, confidence in the ability to identify children at risk for reading difficulties prior to reading instruction is dependent on phonemic awareness assessment in young children (Torgesen, 1998; Wagner, Torgesen, Rashotte, Hecht, Barker, Burgess et al., 1997).

Many linguistic abilities are essential to reading, but in the earliest stages, a critical language skill involves phonemic awareness, which is the understanding and manipulation of sounds in spoken words. Roth and colleagues (2002) identified variables related to structural language; narrative discourse and metalinguistics were significant predictors of early reading, as well as that word retrieval is associated with comprehension ability in later grades.

Children who struggle with phonemic awareness often have difficulty learning to read (Spear-Swerling, 2007). Phonological short-term memory may influence learning letter-sound correspondences and in storing generated phonological sequences prior to blending and output during phonological recoding (Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005). In addition, phonemic awareness is needed to build on fluency and comprehension skills (Muter, Hulme, Snowling & Stevenson, 2004; Spear-Swerling, 2007). Phonological short-term memory is vital to providing a solid foundation for early reading skill development.

Regarding early mathematic skills, the visuospatial sketchpad has been found to be important in predicting arithmetic calculation performance in younger children, with

the central executive predicting mathematics problem solving skills (Rasmussen & Bisanz, 2005). Researchers have found visuospatial working memory to be a significant predictor for preschool children in the performance of nonverbal arithmetic problems (Rasmussen & Bisanz, 2005; Swanson, 2006). Preschool children tend to solve nonverbal problems by using a mental model to represent objects and arithmetic manipulations on these objects (Rasmussen & Bisanz, 2005).

The visuospatial sketchpad's role in early mathematics acquisition appears to change during childhood development. Visual-spatial abilities are more important for early number skill acquisition in preschool children. However, verbal working memory becomes the best predictor of arithmetic performance by the end of first grade. At this stage, children are more likely to encode and solve problems verbally, using the phonological and central executive components of working memory (Swanson & Sachse-Lee, 2001).

Much research has currently centered on the hypothesis that developmental working memory skills are the foundation of individual differences in learning ability (Alloway, Gathercole, Willis & Adams, 2004; Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005; Alloway, Gathercole, Adams & Willis, 2005; Baddeley, Gathercole & Papagno, 1998; Swanson & Sachse-Lee, 2001; Swanson & Jerman, 2007). Research indicates there is evidence linking working memory functions such as the phonological loop, including the phonological store and articulatory rehearsal process, to language acquisition and early reading skills (Baddeley, Gathercole & Papagno, 1998). The visuospatial sketchpad has been linked to arithmetic calculation in early childhood, with central executive predicting mathematics problem solving skills.

There is much literature regarding assessment of working memory components and specific skill acquisition across various ages of childhood. More empirical evidence is needed to support the application of neuroscience principles to school readiness practices, specifically in regards to screening assessments, working memory and early academic performance. Dehn (2008) recommends that more age-appropriate early childhood short-term and working memory measures are needed to screen preschoolers at risk for language and literacy difficulties. If a child enters school with a delay or deficit in working memory, vital early skill attainment may be hindered. As an extension of this idea, it is hypothesized that kindergarten readiness screening results could be examined for working memory weaknesses and possible links to readiness skill performance.

The relevance of working memory components is dependent on the child's developmental stage. The visuospatial aspect of working memory is correlated with all early skill acquisition. The phonological aspect of working memory is related to early reading skills in children younger than 9 years old. After this age, the central executive plays a greater role in the working memory process and learning (Gathercole, 1998; Swanson & Siegel, 2001). Thus, examination of developmental working memory and early academic skills in kindergarten aged children should focus on the visuospatial and phonological components of this important neurobiological process. A deficit in either of these areas could impact early learning, as well as further development of working memory (Baddeley, Gathercole & Papagno, 1998; Gathercole, 1998; Gathercole & Alloway, 2008).

Empirical evidence linking phonological and visuospatial working memory on kindergarten screening assessments to early reading and math skill performance could

provide an initial starting point for intervention as a child enters school, rather than waiting for later kindergarten curriculum based assessment results. In addition, such empirical evidence may provide educators with awareness of individual early working memory aspects in order to provide direct teaching of rehearsal strategies, mnemonics and other working memory strategies to improve efficiency and maximize future learning (Gathercole & Alloway, 2008; Gathercole, Lamont, & Alloway, 2006).

In this study, kindergarten screening subtests representing the phonological loop and visual-spatial sketchpad will be examined in relation to early academic skill probes. Specifically, the Memory for Sentence subtest and Visual Memory subtests from the Kindergarten Diagnostic Instrument, Second Edition (KDI-2; Miller, 2000) will be used. This screening instrument was constructed to identify normal aspects of a child's development, as well as to provide information to help target potential problems with early intervention and prevention as key (Miller, 2000).

The academic skill probes will be taken from AIMSweb kindergarten curriculum-based measurement probes for the Test of Early Literacy Measures (TEL) and Test of Early Numeracy Measures (TEN). AIMSweb is a benchmark and progress monitoring system based on direct, frequent and continuous student assessment (Clarke & Shinn, 2002; Shinn & Shinn, 2002). The TEL is comprised of subtests measuring Letter Naming Fluency, Letter Sound Fluency and Phoneme Segmentation. The TEN includes Number Identification, Quantity Discrimination and Missing Number subtests. In addition, the kindergarten screening results on the KDI-2 will be examined in relationship to the AIMSweb academic probes to determine if there is a correlation with kindergarten screening results and early skill performance during the kindergarten year.

Problem Statement

Understanding specific working memory processes in the development and prediction of early reading and math skills could provide a framework for structuring interventions as a child enters school in order to maximize the learning process. This study represents an initial effort to analyze kindergarten developmental screening results in conjunction with early academic reading and math probes, and may aid in identifying patterns of strengths and weaknesses for future educational planning and intervention. Such information may lead to further development of more specific working memory screening aspects in the kindergarten screening process.

Research Questions and Hypotheses

Research Question 1: What is the relationship between the phonological aspect of the working memory construct and early reading skill measures, taking into consideration gender, prior preschool experience and socioeconomic status?

Hypothesis 1: Children ages 4 to 6 experiencing difficulty with the phonological aspect of developmental working memory will show early reading skill deficits in the form of phonemic awareness, including letter naming fluency, letter sound fluency and phoneme segmentation fluency, taking into consideration gender, prior preschool and SES.

Research Question 2: Is there an interaction between the phonological aspect of the working memory construct and early reading skill measures across time during the kindergarten year?

Hypothesis 2: There will be an interaction between phonological aspect of working memory and early reading skill measures across time during the kindergarten year.

Research Question 3: What is the relationship between the visual aspect of the developmental working memory and measures of early math skills, taking into consideration gender, prior preschool experience and socioeconomic status?

Hypothesis 3: Children demonstrating visual memory deficits will show weaknesses in early math skills such as acquiring mental representations of objects, number concepts and shapes such as number identification, quantity discrimination and missing number, taking into consideration gender, prior preschool and SES.

Research Question 4: Is there an interaction between the visual aspect of the working memory construct and early math skills measures across time during the kindergarten year?

Hypothesis 4: There will be an interaction between visual aspect of working memory and early math skill measures across time during the kindergarten year.

Research Question 5: What is the relationship between kindergarten screening skills and early academic progress, taking into consideration Response to Intervention and Instruction (RtII) Tier placement for Fall?

Hypothesis 5: Children demonstrating average performance on specific kindergarten screening instrument subtests, including phonological and visual aspects of developmental working memory, will demonstrate average progress on early academic skill probes and be placed on Tier I for universal interventions.

CHAPTER 2

LITERATURE REVIEW

The aim of the chapter is to summarize how working memory relates to neurobiology and memory function in the brain, how this process develops in young children and the impact of working memory on early academic skill acquisition. The history of brain-based education and application to school readiness is reviewed, as well as some specific theories of working memory. Recent research regarding working memory in regards to the development of reading and math skills in young children is examined. Implications for school professionals in understanding the relationship of working memory to early learning, as well as in designing instruction and interventions that may maximize the learning potential of each child will be discussed.

Historical Significance of Working Memory and Learning

Brain-based education initiatives

In the 19th century, psychology was considered to be a part of philosophy, not a separate discipline. At Harvard University, in the 1890's, William James was one of the first psychologists to address the application of psychology to classroom teaching and learning. He stressed the importance of adapting classroom instruction to the learner. James stated: "Psychology is a science- teaching is an art; and sciences never generate arts directly out of themselves. An intermediary inventive mind must make the application, by use of its originality". One hundred years after James' death, his idea of using science to improve the art of teaching is finding root in brain-based education initiatives (Sprinthall, Sprinthall & Oja, 1999).

In 1983, Leslie Hart proposed a model of learning that was based on connections between brain function and education practice. In *Human Brain and Human Learning*, Hart wrote that learning is greatly influenced by cognitive processes (1999). In the past 30 years, a field has emerged known as brain-based education. This model uses research in neuroscience on how the brain functions to increase understanding of learning and apply this knowledge to the classroom (Madrazo & Motz, 2005). According to Jensen (2008), brain-based education is the “engagement of strategies based on principles derived from an understanding of the brain.” Brain-based research focuses on such issues as sensory perception, attention, emotions and memory.

Learning is a process in which the brain responds to the environment. Biologically, learning is the formation of new synapses and branching dendrites (Zull, 2002, in Madrazo & Motz, 2005). These biological changes occur at a high rate in young children, so the potential for learning is remarkable. However, the environment must be conducive to forming the necessary brain connections. Recent studies indicate that the brain has plasticity, which is the ability to change as a result of experiences through active, personal and engaging learning activities. (Madrazo & Motz, 2005). Research supports this premise and thus, brain-based education is proving to be the future of effective learning (Jensen, 2008). Understanding the brain mechanisms associated with learning provide a promising direction for brain-based education research and the development of interventions to maximize learning potential.

It should be noted that learning and retention are different concepts. Learning involves the brain and nervous system interacting with the environment. Retention requires that the learning process is given conscious attention and conceptual frameworks

for storage (Sousa, 2006). Such storage is referred to as memory. Memories are formed when multiple pathways in the brain are activated by language, sensory-motor input, spatial-temporal activities, music, art and emotion. Development of memory and specific neurological pathways are discussed in detail later in this chapter.

A current research topic of interest is how working memory is correlated with learning. Working memory is the ability to hold and manipulate information in the brain over short periods of time (Alloway, 2006). This ability is vital because it provides a mental “workspace” where information can be held while engaged in learning activities. Research findings point towards a close relationship between school achievement and working memory skills (Alloway, Gathercole, Willis, & Adams, 2004; Gathercole, S. E., & Pickering, S. J. (2000). Understanding how memory works and functions in the learning process is important in structuring learning needs and designing interventions from the time a child enters school.

School readiness, assessment and intervention

Along with brain-based initiatives, accountability is an imperative issue in current educational practice. The No Child Left Behind Act of 2001 (NCLB) mandates that all children need to know how to read by the end of grade 3. NCLB is the latest federal legislation which enacts the theories of standards-based education reform, formerly known as outcome-based education. Standards-based education is based on the belief that setting high standards and establishing measurable goals can improve individual outcomes in education. The Act requires states to develop assessments in basic skills to be given to all students in certain grades if those states are to receive federal funding for

schools. NCLB does not mandate a national achievement standard; standards are set by each individual state.

The NCLB mandate has led to increased academic expectations for children entering school. The legislation provides funding for states for repeated assessment of student progress in grades K through 3, as well as development of research based essentials regarding reading instruction. In addition, Early Reading First grants provide quality early education to preschool children at risk for reading difficulties. As a result, schools are using readiness screening to determine prerequisite skills for early learning. Screening results can be used to group children, plan for instruction, or make recommendations about school placement (Brassard & Boehm, 2007).

Different states and project definitions of school readiness stress varying aspects of child development, environment, and school involvement in their definitions. The National Education Goals Panel (NEGP) definition, widely accepted, identifies five dimensions of early development and learning that are important in school readiness. These dimensions include physical well-being and motor development, social and emotional development, approaches to learning, language development, and cognition and general knowledge. In their Goals 2000: Educate America Act, Congress defined three elements of school readiness. Readiness in school includes smooth transitions between home/early childhood program and school. Family and community supports include access to high quality programs, parents who support children's learning and communities that support and train parents (Mehaffie & McCall, 2002).

Assessment procedures for young children generally focus on the readiness dimensions defined by the NEGP. However, differences in assessment instruments used

are found in the theoretical view and purpose of the person or school system completing the evaluation. There is significant overlap in the content of the assessments used for developmental screening, instructional screening, assessment of readiness or in-depth assessment. Although there is overlap, developmental screening instruments and readiness tests are not interchangeable according to Meisels (in Brassard & Boehm, 2007). Poor performance on a readiness test may reflect limited learning experiences rather than an inability to acquire knowledge. However, developmental screening instruments are designed to provide information about where the child's developmental path may be off track and used to design interventions to address these areas (Brassard & Boehm, 2007; Mehaffie & McCall, 2002).

In the book *School Readiness and the Transition to Kindergarten*, Blair et al. (2007) examine the application of neuroscience contributions to the study of school readiness. More specifically, the authors focus on executive functioning or working memory in relation to cognition and behavior. Not only are the overlapping cognitive functions of working memory, inhibitory control and attention shifting viewed as foundations of school readiness, but understanding working memory and academic abilities are important to designing appropriate interventions. Research indicates there is evidence linking working memory skills to early learning but more empirical evidence is needed to support the application of neuroscience principles to school readiness practices.

Some specific working memory theories in research literature are reviewed in the next section, with the most cited model discussed in more detail. Application of this theoretical model to child development and early academic skills will then be examined.

Theoretical Models of Working Memory

A review of literature involving working memory is not always clear-cut in nature due to the blurred lines of working memory and short-term memory. In the late 1800's, William James proposed there were two types of memory. He labeled these primary and secondary memories. James described primary memory as the "conscious present" and secondary memory as the amount of information stored over a lifetime. Primary memory can be thought of as short-term memory with secondary memory being considered as long-term memory (James, 1890; Dehn, 2008).

In 1949, Hebb proposed the idea that the brain is divided into two separate systems of temporary and permanent storage. His division of memory was supported by case studies of acquired brain injury (Dehn, 2008). Hebb hypothesized a distinction between short-term memory, based on temporary neural activation, and long-term memory, based on neural growth. A decade later, support for this division came from studies showing that small amounts of information were rapidly forgotten unless actively rehearsed (Baddeley, 2003).

Recent studies in adults view working memory as being distinct from short-term memory, but highly related. Swanson (2008) cites Engle as finding that short-term memory and working memory tasks loaded on two different factors and that a two factor model fits the data better than a one -factor model. This means that when comparing the results of short-term memory and working memory tasks, statistical models are used to determine how the tasks best represent each construct. If all the tasks fit well together, they would all be representative of working memory in general, or a one factor model. The research by Engle showed that some tasks are better representative of short-term

memory, and others are more indicative of working memory. Thus a two factor model best describes how memory works, as well as short-term memory and working memory are separate, but related processes. Studies in children indicate that short-term memory and working memory load on the same factor (Swanson, 2008). This one factor loading may be due to the developmental aspect of working memory. Swanson suggests that because younger children are less efficient in the processing of phonological information, this can blur the distinction between measures of the verbal processing and the executive system.

Researchers emphasize different aspects of memory structure and formation in the working memory construct. However, most researchers agree that the frontal cortex, parietal cortex, anterior cingulate, and parts of the basal ganglia are important in working memory function (O'Reilly, Braver, & Cohen, 1999; Shah & Miyake, 1999; Sohlberg & Mateer, 2001). Because working memory is a construct involving attention and short-term memory encoding, and long-term memory retrieval, researchers have proposed various models to explain how this process functions in learning.

Overview of working memory theories

There is considerable controversy in research literature regarding whether working memory is a unitary or non-unitary construct. The unitary construct view holds that one component takes multiple roles in storage and processing of short-term and long term memories. Non-unitary model proponents hypothesize many processes interact to form working memory. However, in the non-unitary school of thought, different researchers fractionate working memory in different ways, with much variation in the number of subsystems and nature of each subsystem (Shah & Miyake, 1999).

Daneman and Carpenter theorized that individual differences in working memory are due to the individual mental resources that are available (Dehn, 2008; Shah & Miyake, 1999). These researchers proposed that working memory is undifferentiated and can be used to support temporary storage or long-term processing. They contend that complex mental operations rely on working memory resources and the more efficient the mental processing; the more resources are available for short-term storage. Just and Carpenter extended this model to language development. They advocate that linguistic working memory capacity directly constrains the operation of language comprehension processes and that variation in the capacity of linguistic working memory within the normal population is the source of individual differences in language comprehension (MacDonald & Christiansen, 2002).

Cowan (1999) views working memory as being organized into two embedded levels of activated long term memory and the focus of attention in the activated memory. Known as the Embedded Processes Model, this view holds that working memory is comprised of the cognitive processes that retain information in an accessible state for carrying out any task with a multiple component. According to Cowan, information enters through a sensory channel and passes to one of three levels of memory or activation. The levels include long-term store, activated or short-term memory and focus of attention.

This model emphasizes focus of attention, levels of activation and expertise as vital properties of working memory. Cowan proposes that a limited focus of attention restricts working memory retention and processing, not storage capacity. The focus of

attention can handle three to five chunks of activated information depending on the complexity, but the activated memory does not have such limits (Dehn, 2008).

Following Cowan, Kane, Engle and fellow researchers view working memory as an integrated memory and attention system made up of long-term memory and executive attention processes. In this model, working memory is an executive attention function that is distinguishable from short-term memory. Engle, Kane and Tuholski (1999) theorize that working memory is a system of long-term memory, limited capacity for attention, many domain specific codes (such as the phonological loop and visuospatial sketch pad) and individual differences. Domain-general, executive components of the working memory system function to support a wide range of cognitive abilities (Kane, Conway, Hambrick & Engle, 2008). Kane and Engle propose that working memory capacity is not about short-term memory span, but rather the ability to control attention to maintain information in an active, quickly retrieved state (Dehn, 2008).

Oberauer has extended the Cowan model (Oberauer, Süß, Wilhelm & Sander, 2008) to add a third level involving a more narrow focus of attention that only holds one chunk at a time for processing and then shifts the attention focus to the next chunk of information. Considered to be a facet model, Oberauer used structural equation modeling of working memory tasks to arrive at two dimensions comprised of multiple parts. The first dimension is the content facet which consists of a verbal and numerical factor, as well as a figural and spatial factor. The second dimension is functional storage in the context of processing, coordination and supervision or switching (Dehn, 2008). This model is similar to Baddeley's model in terms of the fractionated central executive

processes of dual task coordination and switching, separate verbal and visuospatial processes and storage processes.

Baddeley and Hitch model

Probably the most frequently cited model of working memory is that of Baddeley and Hitch (Baddeley, Gathercole & Papagno, 1998; Baddeley & Logie, 1999). Their model represents an elaboration of earlier unitary models of short-term memory proposed by Broadbent in 1958 and Atkinson and Shiffrin in 1968 (Baddeley & Hitch, 2000). This multi-component construct theorizes that there are two “slave systems” responsible for short-term encoding and maintenance of information, and a “central executive” responsible for supervision of information integration and coordination of the slave systems. Baddeley (1999) emphasizes that the exact nature of these components is an empirical question, rather than an a priori assumption of the model.

One slave system, the phonological loop, deals with verbally coded information. Baddeley (2003) proposed that the phonological loop evolved to facilitate language acquisition. Since the original model proposal in 1974, the phonological loop has been fractionated into a phonological store for verbal information and an active rehearsal process in which the verbally coded information is practiced to prevent decay of the phonological representation. The phonological store represents information in a phonological code, which decays over time. Immediate memory span declines as the word length increases from one to five syllables. The rehearsal process, often referred to as the articulatory control process, acts to restore the decaying information in the phonological store. This process is similar to subvocal speech. The capacity of the phonological store is limited to a few seconds. However the information can be refreshed

so it stays accessible in the loop. Information that enters the phonological loop is rehearsed through sub-vocal rehearsal (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998).

When the capacity of the loop is exceeded, rehearsal is disrupted and information is lost. Rehearsal can be disrupted by articulatory suppression, phonological similarity or increased word length (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998). When subvocal rehearsal is prevented by having a person continuously repeat a sound or word, articulatory suppression occurs. Similarity of words can result in similar sounding words overlapping in the rehearsal process and disrupt retention. Increased word length increases the amount of time required for rehearsal and also disrupts the process.

The visuospatial sketchpad, which stores visual and spatially encoded information, is the second slave system. Logie has proposed fractionation of the sketchpad into a passive visual cache and active spatial construct called the inner scribe (Baddeley, 2003; Baddeley & Logie, 1999; Pickering, Gathercole, Hall & Lloyd, 2001). It has been suggested that there are two visual processing paths for object and spatial codes, comprising the “what” and “where” of visual information. Logie argues that sketchpad is not a perceptually-based storage mode, but occurs after visual information has been processed in long-term memory (Baddeley, 2003).

Visual working memory is limited in capacity to about three or four objects. Features of objects such as color, location and shape compete for storage capacity. Like the phonological loop, similar features can overlap and disrupt retention (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998). Recent evidence points toward a dissociation between the capacity for retaining visual patterns and sequences of movements.

However, as discussed in the development of working memory section, this dissociation may be due to the capacity of these systems to develop at different rates (Baddeley & Logie, 1999). There is empirical evidence to support the visuospatial sketchpad (Pickering, Gathercole, Hall & Lloyd, 2001; Jonides, Smith, Koeppe, Awh, Minoshima, & Mintun, 1993), but less evidence of fractionation.

Baddeley (2003) considers the central executive to be the most important but least understood component of working memory. The central executive system is responsible for directing attention to relevant information, suppressing unimportant information and for coordinating cognitive process when multi-tasking. The original model assumed that the central executive stored information, but this idea has evolved into the belief that the total storage capacity beyond the slave systems is achieved by accessing long-term memory or other subsystems. Due to evolving research findings, the view of the central executive is constantly being refined. Additional postulates regarding executive functions include focusing and switching attention, as well as activating representations in long-term memory (Baddeley & Logie, 1999).

In 2000, Baddeley added a fourth component, the episodic buffer, to this working memory model. The original three-part model was deficient in addressing interaction with long-term memory as well as a system for “chunking”, allowing information in long-term memory to increase immediate recall. Chunking increases immediate memory span from 5 to 6 unrelated words to sentences of about 15 words (Baddeley, 2003).

The role of the episodic buffer is to hold representations and integrate phonological, visual and spatially encoded information, as well as perceptions not included in the slave systems such as semantic or musical information. The episodic

buffer has been described as a structural alternative to the idea of a long-term memory framework (Ericsson & Delaney, 1999; Towse & Hitch, 2008). This distinction between short-term memory and long-term working memory accounts for the ease with which familiar stored knowledge can be accessed and used to expand learning experiences. The greater the knowledge is in a particular area, the greater the working memory capacity for information in that area (Baddeley & Logie, 1999).

An early limitation to the Baddeley and Hitch working memory model was that it explained simple memory-based tasks better than more complex cognitive processes. The addition of the episodic buffer offers a way to consider such complex cognitive activities in regards to development (Baddeley & Hitch, 2000). The concept of the episodic buffer as common unified storage makes this model more compatible with working memory views based on individual differences, which have emphasized the executive process (Baddeley, 2003).

Neurobiological evidence of Baddeley and Hitch model

Much of the development of the Baddeley and Hitch model of working memory has been derived from studies of brain-damaged patients. For example, Della Sala and Logie (Baddeley & Logie, 1999) examined lesion sites in patients with verbal short-term memory deficits, finding that the majority of lesions were in the left hemisphere. Lesions in the lower part of the parietal lobe close to the junction with the upper part of the posterior temporal lobe were found in patients with impaired digit span (Warrington, James & Maciejewski, 1986; Baddeley & Logie, 1999). The supra-marginal gyrus has been identified as the damaged area in cases of verbal short-term impairment (Warrington, Logue & Pratt, 1971; Baddeley & Logie, 1999).

Regarding the visuospatial sketchpad, right hemisphere lesions are commonly associated with visuospatial memory impairments (Baddeley & Logie, 1999). There appears to be a distinction between the lesion sites associated with visuospatial working memory deficit and lesions linked with visual imagery deficits.

Neuroimaging results indicate that the phonological loop and the rehearsal process operate at a deep and central level. Baddeley (2003) states phonological loop activity is associated with left-hemisphere activation, with Brodmann's area 40 associated with phonological storage and Broca's area associated with subvocal rehearsal. However, other researchers Baddeley, Gathercole & Papagno, 1998; Gathercole, Pickering, Ambridge & Wearing, 2004) describe the phonological loop storage as served by a neural circuit in the left hemisphere spanning inferior parietal areas with rehearsal being associated with anterior temporal frontal areas. Still other researchers (Baldo & Dronkers, 2006) have recently reported the supra-marginal gyrus supports the phonological store and Broca's area is associated with articulatory rehearsal. Despite differences in brain mapping, division between the phonological loop and rehearsal process is supported by experimental, neuropsychological findings and recent neuroimaging studies (Baddeley, Gathercole & Papagno, 1998; Baddeley & Logie, 1999)

Examination of visuospatial working memory tasks using positron emission tomography (PET) studies of the normal brain have indicated activity in the right hemisphere with specific active areas of the hemisphere dependent on the task (Dehn, 2008). Neuroimaging studies indicate the right hemisphere is active in visuospatial working memory, especially in the right occipital and inferior frontal lobes (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998). Such studies have also provided evidence

that the visuospatial fractionations of storage and rehearsal are indicated by separate neural systems. There is also evidence that the visuospatial sketchpad is divided into the visual area located in the occipital lobes and the spatial area located in the parietal lobe (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998; Dehn, 2008).

The central executive, core of the working memory process, is associated with the prefrontal cortex. A recent finding regarding the role of this area of the brain in executive function is that performing a language task (using semantic judgment) and a visuospatial task (using mental rotation) simultaneously may require the prefrontal cortex that is not necessarily needed to complete the separate tasks (Baddeley & Logie, 1999). Imaging studies indicate working memory demands cause significant increases in dorsolateral prefrontal cortex activity compared to non-working memory tasks.

PET studies using short-term memory tasks that require maintenance of information across short delays indicated little frontal lobe activation. Activation that does occur is centered in ventral areas such as Broca's area, the pre-motor cortex, and supplemental motor areas (Engle, Kane & Tuholski, 1999). However, additional studies that required information to be retained across longer delays, or to shift attention between storage and processing functions, such as the "N-back" task, indicated prefrontal cortex activation. Existing data shows dorsolateral prefrontal cortex function is activated in behavioral tasks that require retention of information across shifts of attention. (Engle, Kane & Tuholski, 1999). Finally, individual differences in working memory capacity can be mediated through differences in prefrontal cortex function.

Although there is the least amount of evidence to support the episodic buffer, a 2007 study by Rudner, Fransson, Ingvar, Nyberg and Rönnerberg looked at neuroimaging

data. They found that the left hippocampus and posterior regions including the right middle temporal lobe are involved in episodic buffer processing.

Consideration of theory and biological basis provides a foundation for viewing working memory functions in general. However, differences in working memory occur across developmental stages. Foundations of memory formation and neurobiology are reviewed before considering the developmental nature of working memory.

Memory Stages, Types and Neurobiology

Memory Stages

Understanding the specific stages of memory is useful in the review of working memory literature. The first stage of memory formation is attention, which involves alertness, arousal, concentration, and selectiveness. Encoding, which involves the receiving or entering of information, is also part of the initial stage of memory. Storage is the second stage in the creation of a permanent record or file of such information. Decay occurs when encoded information is not permanently stored, which can occur quickly or slowly depending on the type of memory. Retrieval, or recall, is the last stage in effective memory creation. Retrieval is the ability to access the stored information for use in application to new learning. Attention to perceived information is encoded, stored and processed in the brain as memories. The type of information entered the conditions under which it is entered, how it is stored and processed form different type of files or memories.

Duration and capacity are also important in the classification of memory (Gathercole & Alloway, 2008; Sohlberg & Mateer, 2001). Duration refers to the length of time information is held in storage and capacity refers to the amount of information that

can be stored. When information is encoded using short-term memory, it only lasts for a few minutes with 3 to 5 items being held in storage. Long-term memory has unlimited storage capacity with no decay. The goal of specific interventions should be to facilitate short-term memory in order to increase long-term memory.

Memory Types and Neurobiology

Various systems and structures in the brain influence varying aspects of memory formation. Understanding brain function is foundation to understanding how to maximize memory, as well as how to facilitate the learning process.

Although not discussed in great detail in literature reviews because of limitations in gathering empirical data, sensory memory refers to the ability to experience and process information for only fractions of a second. Cowan (1999) reports that neuroimaging studies show modality-specific activity in the cortex. This type of memory cannot be prolonged with rehearsal, however, preferred sensory input can aid in short-term and long-term memory storage.

Gathercole and Alloway (2008) outline additional types of memory. Short-term memory lasts for only a few seconds. This form of memory is supported by transient patterns of neural communication in the parietal and frontal lobes, especially the dorsolateral prefrontal cortex (O'Reilly, Braver, & Cohen, 1999). Short-term memory is formed primarily by acoustic stimuli, which is related to verbal acquisition, or visual coding. Studies in brain imaging and cognitive neuropsychology have shown that brain areas and memory systems regarding verbal and visuospatial short-term memory are separate.

Verbal short-term memory involves the left-hemisphere regions of Broca's area and the prefrontal cortex. Because Broca's area is important to expressive language, as well as processing syntax, or the rules of language, children with expressive language difficulties may not benefit from verbally presented information. Such children need visual cues paired with verbal instruction. Visual short-term memory is associated with the parietal and prefrontal areas of the right hemisphere (Gathercole, 1998). Parietal deficits include understanding visuospatial concepts. Understanding of how memories are formed by parts of the brain is important in planning interventions to maximize learning.

Long-term memory is formed by encoding of experiences over time and also by knowledge that has been acquired through extensive rehearsal (Gathercole & Alloway, 2008; Shah & Miyake, 1999). Different kinds of long-term memory, which are dependent on specific psychological processes, can be considered to be declarative (explicit) or nondeclarative (implicit).

Declarative memory is explicit to a person's individual knowledge base and includes episodic, autobiographical and semantic memory (Sohlberg & Mateer, 2001). Episodic memory lasts for longer periods of time and contains details of specific experiences. The encoding of this type of memory is specific to mental interpretation of time or place, and fades unless retrieved and rehearsed. The duration for autobiographical memory, made up of facts such as personal information and conceptual knowledge, can last a lifetime. The earliest distinct autobiographical memory generally dates back to age three or four years. Semantic memory, which also can last a lifetime, allows for the encoding of information of abstract knowledge through personal experiences. An important part of semantic memory is the mental lexicon of language and concept

(Gathercole & Alloway, 2008). There is a growing body of evidence that semantic memory is associated with the temporal lobe (Hale & Fiorello, 2004).

Nondeclarative or implicit memory involves the learning of a specific skill. Priming refers to the idea that cues prompt recall (Sohlberg & Mateer, 2001). Procedural memory occurs when learning skills become automatic. The duration of such memory last across a lifetime, once a skill set is established (Gathercole & Alloway, 2008).

Long-term memories are maintained by more permanent changes in neural connections throughout the brain. There is a growing body of evidence that semantic memory is specifically stored in the temporal lobe. Research indicates that long-term memory for learned information is associated with the left temporal lobe, while memories for hearing, vision, somatosensory and motor functions are related to the brain areas that perform those functions (Hale & Fiorello, 2004). Procedural memory is generally dependent on the cerebellum and basal ganglia. The hippocampus, although it does not store information, is essential for the consolidation of information from short-term to long-term memory. The amygdala is thought to be involved with emotional aspects of memory (Hale & Fiorello, 2004; Sohlberg & Mateer, 2001).

Working memory refers to the system of inter-linked memory components located in different parts of the brain as discussed in the neurobiology of memory formation. In general, working memory begins with the attention process along with encoding of information through short-term acoustic, verbal or visuospatial input (Gathercole & Alloway, 2008). Working memory is temporary in function, which is helpful for updating the constant input of information that is attended to on a moment-to moment basis, and facilitating the storage of important information when necessary. The contents

of working memory are combined to store perceived information, as well as manipulated, interpreted and assimilated to form new knowledge (Logie, 1999).

Understanding working memory development in children is important to facilitate early childhood learning. In the next section, the development of working memory in young children is reviewed in context of current research.

Development of Working Memory

Birth to Age Two

The function of working memory is best understood in the context of childhood developmental theory. According to Piaget, from birth to age two is the sensory motor stage. An infant's first experience of the world is primarily sensory, and thus, sensory memory would be the initial form of memory experienced by the brain. Although this form of memory exists for only a brief second, the cortical stimulation of the baby's brain is vital in the developmental process. In keeping with developmental theory, critical points in brain development are necessary for future learning. At this stage, it is important to provide visual, auditory and kinesthetic stimulation to engage the attention process of the baby's brain, encode sensory information and provide opportunities to recall previous sensory experiences.

Studies by Nelson and Xu indicate that pre-declarative memory exists in infants as young as 2 months of age. This has been measured in the length that infants look at familiar faces and objects using memory recognition tasks (Heffelfinger & Mrakotsky, 2006; Nelson, 1993). More mature declarative memory begins to develop around age 1 and continues through the preschool years (Gathercole, 1998; Heffelfinger & Mrakotsky, 2006)

Although the phenomenon known as “childhood amnesia” refers to the idea, reported by Henri and Henri in 1897, that it is extremely unusual to be able to retrieve memories that took place before 2 years of age and that memories for the period between ages 2 and 5 years are infrequent (Gathercole, 2008), the brain processes involved in early sensory memory formation should not be discounted. Autobiographical memory evidence is not easily measured in infancy, but there are studies to suggest that children’s early memories are more episodic in nature, with 2 ½ year old children able to recall events that took place 6 months ago (Fivush, 1984; Gathercole, 1998). Fivush & Hamond use a social-interactional framework to explain their research. They suggest that episodic memory emerges as children learn to talk about their memories. This type of memory development coincides with the end of the sensory-motor stage and the development of object permanence and the onset of rapid language acquisition. A child in this stage of working memory development is able to store the concept of an object or person’s existence in memory, although the object is out of sight. Visual short-term memories are being encoded at this point of development.

Although specific functional aspects of the visuospatial sketchpad have not been as extensively studied as those phonological loop processes, there is a basic understanding of change across age. Younger children are more dependent than older children on using the sketchpad to maintain immediate memory (Gathercole, 1998). This may be due to the idea that this form of memory develops earlier than the phonological loop and requires less rehearsal for encoding information.

Preschool Years

Development of the visual short-term aspect of working memory in the transition period from 1 to 3 years of age was examined from a specific neo-Piagetian view by Alp (1994). An imitation sorting task was designed to assess young children's ability to observe specific objects sorted into two containers and then reproduce the demonstrated sorting. The number of objects in the largest observed and successfully sorted set determined the score. Results indicated an age-related increase in the scores appears to be about one unit for every six months in this age range. Because children in the preschool years are functioning in the pre-operational stage of development, they tend to experience the world through visual images before the acquisition of language. Thus, visuospatial short-term memory is the most appropriate way for learning to initially occur.

Studies by Nelson, Fivish and colleagues (Fivish, 1984; Gathercole, 1998; Nelson, 1983) have indicated that after episodic memory develops in young children, autobiographical memory begins to emerge. This coincides with awareness of social interaction and language development. As children learn to talk about their memories, the rehearsal process in the phonological loop begins to form. Verbal short-term memory provides temporary storage for the sound patterns of language. It can be used to store familiar or unfamiliar words. The information held in storage will decay within seconds. The rapid decay can be prevented for a short time, by rehearsal. Lengthy information is less likely to be stored because it requires significant rehearsal (Gathercole & Alloway, 2008).

The phonological loop component of working memory is strongly associated with research of language acquisition in young children. Studies by Gathercole and Baddeley

have shown that young children's ability to repeat a series of nonsense words at age 3 or 4 years predicts their language ability several years later. This observation suggests that the ability to repeat unfamiliar speech sounds, which is a feature of the phonological loop, is important for vocabulary acquisition and language skills in young children (Logie, 1999). Gathercole & Alloway state that although young children can store verbal information, they do not naturally rehearse until age 7. However, recent research indicates that children can be taught this skill to improve acquisition of verbally presented information.

A link has been discovered between speaking rate and memory span. Logie cites a study in which Welsh-speaking children were observed to demonstrate poorer digit span than English speaking children. This was attributed to the fact that the words for digits in Welsh take longer to pronounce than do the same numbers in English. Logie (1999) cautions that digit span is language specific and interpretation of performance on such tasks in children across language and cultures should be considered in this context.

Rather than coding pictures into phonological form, younger children tend to attempt to remember such memory stimuli in terms of visual characteristics. Visual memory span increases with age. At age 5 years, the mean pattern span of remembered blocks is 4, with the mean block span increasing to 14 blocks at age 11. An adult level of visuospatial memory span is achieved by age 11. (Gathercole, 1998; Gathercole & Alloway, 2008).

At age 4, a child can remember about 2 to 3 unrelated verbal items. At age 13, a child can remember approximately 6 unrelated verbal items. It appears that the phonological store component of the phonological loop is present in very young children,

but the subvocal rehearsal process does not emerge until about 7 years of age (Baddeley & Hitch, 2000; Gathercole 1998; Gathercole & Alloway, 2008). Research has shown that as children develop, they begin to use verbal and visuospatial short-term memory together for more efficient processing. Older children adopt a strategy of verbally encoding pictures and use the phonological loop to mediate performance on visual memory tasks (Gathercole, 1998).

Early School-Age Years

The stage of concrete operations begins at age 7, just about the time the phonological loop is able to verbally code information with automaticity and subvocalize rehearsal patterns to increase memory. Also, at this developmental stage, the ability for children to retain presented knowledge appears to be due to increases in the capacity of the sketchpad to hold material in visual form, as well as increased use of non-visual strategies using the phonological loop and central executive to supplement memory performance (Gathercole, 1998).

Research by Baddeley indicates that the central executive is responsible for control and regulation of cognitive processes including temporary activation of long-term memory, coordination of multiple tasks, shifting tasks and retrieval (Alloway, Gathercole, Willis and Adams, 2004). The capacity to hold information in working memory is closely related to paying attention, as well as related aspects of attention that are needed for effective processing. The ability to sustain focus, inhibit unnecessary information and shift focus is needed for the working memory process to be efficient (Gathercole, 2009; Friedman, Miyake, Young, DeFries, Corley, & Hewitt, 2008). Posner

& Rothbert (2005) write that executive attention shows a strong period of development between 2 and 7 years.

Research has indicated that the developmental functions for the phonological loop, visuospatial sketchpad and central executive are very similar, showing linear increases in performance from 4 years through adolescence (Gathercole, Pickering, Ambridge, & Wearing, 2004). The role of the episodic buffer would come into play at this time, coordinating the task switching and assisting in long-term memory storage. In addition, the episodic buffer incorporates domain specific views of memory (Towse & Hitch, 2008). A study by Hitch, Towse and Hutton (2001) found that working memory span involves a combination of domain general and domain specific resources. However, this finding makes theoretical interpretations of working memory more difficult to evaluate due to individual differences. Such differences can cause significant atypical memory development.

Atypical Development

Children with slow processing due to genetic or birth complications may demonstrate slower language acquisition and poorer working memory skills due to the fact that more time is required to hold verbal-short-term memory in the phonological loop for the rehearsal process before it delays. Thus, young children demonstrating such difficulties should be provided with brief verbal input and taught to rehearse the information to encode it in memory and facilitate learning. Processing of visuospatial information needs to be presented in small, manageable units so the information can be encoded (Alloway, Gathercole, Adams & Willis, 2005; Gathercole, Tiffany, Briscoe & Thorn, 2005).

The fractionation of the phonological loop and the visuospatial sketchpad is useful in analyzing developmental memory deficits associated with various genetic disorders. Children with Down syndrome are more impaired on tasks that involve the phonological loop, which may be correlated with slower language acquisition. However, such children perform relatively well on tasks involving the visuospatial sketchpad (Baddeley, Gathercole & Papagno, 1998; Baddeley & Hitch, 2000).

Children with William's syndrome show an opposite pattern, in which their acquisition of expressive language is less impaired than performance on visuospatial tasks. Such dissociations of functional weakness in working memory may underlie cognitive patterns associated with neurological profiles in young children (Baddeley, Gathercole & Papagno, 1998; Baddeley & Hitch, 2000).

Research cited by Alloway (2007) suggests working memory profiles in children with various developmental disorders. These profiles are consistent with the multi-component model of working memory, as well as specific developmental characteristics of such disorders. Specific Language Impairment is associated with lower verbal-short-term memory, as well as lower working memory skills (Baddeley, Gathercole & Papagno, 1998). However, visuospatial short-term memory functions are generally in the average range. Conversely, Developmental Coordination Disorder is associated with deficits in visuospatial short-term memory and working memory.

Children diagnosed with Attention Deficit Hyperactivity Disorder generally demonstrate intact verbal short-term memory, but verbal and visuospatial working memory is not as strong. In a group of high-functioning children diagnosed with Asperger's Syndrome, poor performance was specific to verbal short-term memory tasks,

with scores in the average range for verbal working memory and visuospatial memory tasks. This finding is interesting because a diagnostic criterion for Asperger's Syndrome indicates no delay in language development. However, the ability to filter unnecessary information, as well as focus on appropriate information, may interfere with verbal short-term memory. Practical application of these findings gives educators a specific area to provide interventions in order to attempt to improve specific sections of working memory dysfunction (Alloway, 2007; Gathercole & Alloway, 2008).

Educational and psychological research findings point toward a relationship between school achievement and working memory skills. Much research has currently centered on the hypothesis that working memory skills and development are the foundation of individual differences in learning ability. If a child enters school with a delay or deficit in working memory, vital early skill attainment may be hindered. More specifically, researchers are investigating possible relationships between young children's working memory and early academic skills in reading and math. Current research regarding reading and math development, as well as working memory in regards to early reading and math skills in children ages 4 to 6 will be reviewed.

Working Memory and Early Reading Skills

Early Reading Development

According to the National Reading Panel (2000), the ability to read requires proficiency in a number of language domains including phonemic awareness, phonics, fluency, vocabulary and text comprehension. The concept of phonemic awareness, or the ability to distinguish and manipulate individual sounds of language, has helped to connect the threads of reading acquisition. Gersten and Chard (1999) write that phonemic

awareness provides greater precision in instruction than application of mere phonics strategies, which rarely include blending or segmentation. Studies have indicated that phonemic awareness is a strong indicator of future reading ability with correlations between phonemic awareness in kindergarten and word-reading skills at the end of first grade falling between .4 and .6 (Torgensen, Wagner & Rashotte, 1994). Phonemic awareness is a key to early reading development.

The origin of reading skills begins long before it is taught formally. Gibson (1970) writes that reading has roots in speech and writing development. Babies learn about spoken language when they hear caregivers talking and respond to the sounds in their environment. Essentially, very young children learn to segment sequential acoustic information, divide it into structural units, discriminate these units and to infer rules that structure these language units. Werker and Tees (2002) demonstrated that infants can discriminate speech sounds according to phonetic category without prior specific language experience. Infants up to age 10 to 12 months can distinguish native and nonnative sounds. After the first year of life, this ability begins to decline. When young children begin to exhibit more adult-like patterns of discrimination, this results in the beginning of native language acquisition. Thus, the perception of sounds results in the beginnings of native language phonology.

Chall (1976) proposed that reading development occurs in stages patterned after Piaget's cognitive development stages, as well as the idea that reading is a form of problem solving in which the child adapts to his/her environment through the processes of assimilation and accommodation. The pre-reading stage exists from approximately age birth through 6 years. Initially, the infant perceives sounds and learns to make sense of

them. This process of language acquisition occurs from about 9 months of age. A young child shows the first signs of word comprehension at around 9 months, and the production of words (especially names for people and objects) around 12-13 months. Words accumulate slowly for the first few months, but the rate at which words are learned shows a sharp acceleration around 16-18 months of age (Fenson, Dale, Resnick, Bates, Thai & Perthick, 1994). At age 2 years, young children show the first signs of phonological awareness by being interested in word play, rhyming and alliterations. This phonological awareness continues to develop until a child enters school. A study by Liberman, Shankweiler, Fischer and Carter (1974) provides direct evidence of a developmental ordering of syllable and phoneme segmentation abilities in the young child. Only about 50% of 4 and 5 year old children were able to tap out the number of syllables in multi-syllabic words, but 90% of the 6 year old children were able to do this.

As children begin to be able to produce the sounds they perceive, they also begin to scribble. As early as 12 months of age, a child given a paper and pencil will make marks on the paper. At 14 months, a child will make a definite scribble. Thus, as speech stems from early aural perception, writing arises from early visual stimulation (Gibson, 1970). The results of a study by Treiman and Rodriguez (1999) indicated that young children search for systematic relations between print and speech from an early age.

Firth (1985) stated that different processes bring about the stages of reading development. In Firth's model, children begin with a logographic approach to reading, by using visual skills to try to read what they have written. Young children at this stage will try to identify whole words by sight. Motivated by the desire to write, children move into an alphabetic phase for spelling, and these alphabetic skills are transferred back into

reading where they allow children to read words they have not encountered previously. As reading skills become more automatic, children rely more on orthographic relationships that exceed simple grapheme-phoneme correspondences and include the use of morphological spelling patterns. Although Firth states that the orthographic phase is non-phonological, it is implied that the child cannot enter into this non-phonological phase without having first passed through the alphabetic phase. Phonological perception is vital to this phase. (Firth, 1985; Snowling, 1998).

A study by Ehri and Wilce (1985) examined the hypothesis regarding the first stage of reading being visual or phonetic. Kindergarteners were grouped according to their ability to read words including prereaders, novices and veterans, or those children who could read several words. These children were taught to read simplified phonetic spellings, in which letters corresponded to sounds, and visual spellings, with letters being more distinctively different. Results indicated that prereaders learned to read the visual spellings more easily than the phonetic spellings. However, novices and veteran readers learned to read the phonetic spellings more easily. These findings suggest that when children begin reading, they shift from visual cue processing to phonetic cue processing. Phonetic processing requires recognizing and remembering the associations between letters in spellings and sounds in pronunciations.

Stuart and Colheart (1988) debate the idea that all children pass through the same reading stages in the same order. They tested the hypothesis that children who are phonologically skilled before learning to read may use their phonological skills from the beginning. Children who are not phonologically skilled may initially approach reading as a visual memory task. Results of this study indicate that phonological awareness and

reading acquisition have reciprocal interactive causal relationship, not a uni-directional one. Phonological skills can play a role in the very first stage of reading skills when children are phonologically adept. Thus, the first stage of reading may not always be non-phonological such as logographic processing.

The statistical relationship between phonemic awareness skills and beginning reading success is robust. In a study completed in 1991 by Ball and Blachman, results indicated that phoneme awareness instruction paired with instruction connecting phonemic segments to alphabet letter significantly improved early reading and spelling skills. The significance of phonemic awareness may extend beyond the development of early reading and spelling skills. The failure to provide early phonemic awareness training to children with poor segmentation skills can have a negative effect on the early reading process (Torgesen, 1988).

It should be noted that many intervention studies indicate that children with average development benefit more from phonemic awareness instruction than children at risk for learning difficulties or cognitive impairments (Swanson & Jerman, 2007; Swanson & Siegel, 2001). However, there is an emerging foundation of empirical evidence that suggests more intensive interventions at the kindergarten level, as well as longitudinal intervention may be beneficial to all children (Gersten & Chard, 1999).

Early Reading Skills and Working Memory

Working memory is required when learning because skill acquisition needs short-term memory, interaction with long-term memory, as well as simultaneous storage and processing of information. More specifically, there is considerable evidence that the phonological loop has an effect on long-term phonological learning. Baddeley (2003)

cites patients with short-term memory deficits as having impairments in the capacity for new phonological learning. Normal subjects show impairment in new phonological learning when performing simultaneous tasks that are interfering with the rehearsal process of the phonological loop. In addition, learning involves the development and modification of phonological representations, implying that language acquisition has an important connection with the phonological loop (Baddeley & Logie, 1999).

Phonemic awareness is necessary when learning to decode, or use letter-sound relationships to read unfamiliar words, and is highly dependent on spoken language awareness. Phonic awareness is related to written words. Both skills are needed to develop reading comprehension. Phonemic and phonic awareness influence reading fluency because when a child struggles to read each word in a sentence, fluency and comprehension suffer (Muter, Hulme, Snowling & Stevenson, 2004; Spear-Swerling, 2007).

Research from cognitive psychology, linguistics and education has expanded understanding of how children learn to read and why some children experience reading difficulties. Much research is concentrated on the earliest stages of reading in the preschool period and primary grades. Findings indicate that learning to read depends greatly on language acquisition abilities. Many linguistic abilities are essential to reading, but in the earliest stages, a critical language skill involves phonemic awareness, which is the understanding and manipulation of sounds in spoken words. Children who struggle with phonemic awareness often have difficulty learning to read (Spear-Swerling, 2007).

A longitudinal study examined the relationship between oral language and early reading acquisition (Roth, Speece & Cooper, 2002). A group of normally developing

kindergarten children was followed for three years with structural language, metalinguistics, and narrative discourse, along with print awareness, letter-word identification, pseudoword decoding, word attack skills and passage comprehension. Using regression modeling, the researchers identified variables related to structural language; narrative discourse and metalinguistics were significant predictors of early reading.

Roth, Speece & Cooper (2002) also found that word retrieval was associated with comprehension ability in later grades. The authors noted that word retrieval involves the phonological processing component and concluded that word retrieval influence on reading comprehension represents semantic and phonological knowledge.

Baddeley (2003) states that the phonological loop should facilitate language acquisition by storing temporary representation for new phoneme sequences and the articulatory system should facilitate learning through rehearsal. Thus, this short-term processing component of verbal information is needed for language acquisition which is the foundation of reading development. In a study of working memory and phonological awareness as predictors of progress for early learning skills, Alloway, Gathercole, Adams, Willis, Eaglen & Lamont (2005) found that capacity to store and process information over short periods of time and the awareness of phonological structure may play a critical part in the early learning for children. There was a significant effect size between various complex memory tasks, phonological short-term memory, episodic buffer, and phonological awareness and reading skills as measured on a local achievement assessment used to assess progress towards learning goals.

Chiappe, Hasher, and Siegel (2000) examined the relationships between working memory, inhibitory control and reading skills in children and adults. In addition to a standardized measure of word recognition, the subjects were given a working memory task in standard blocked format (three sets containing 2, 3, 4 item trials) or in a mixed format (three sets containing 2 trials, 3 and 4 item trials) to determine whether scores obtained on standard format are influenced by proactive interference. Intrusion errors were examined in order to determine whether deficits in working memory were associated with the access, deletion, or restraint functions of inhibitory control. Deficits in working memory in young children can result from smaller working memory capacity in addition to difficulties in restrictive access to relevant information in the working memory system and lead to reading difficulties in later grades.

In 2004, Alloway, Gathercole, Willis and Adams used path analysis to describe a modular structure that includes an episodic buffer distinct from both the central executive and phonological loop in children, aged 4 to 6 years, starting school. However, additional findings indicated that early phonological awareness and short-term memory skills are relatively distinct in young children, but converge over the early school years as a result of their contributions to literacy development.

This distinction may be useful in understanding the nature of early reading development. Phonological short-term memory may influence learning letter-sound correspondences and storing generated phonological sequences prior to blending and output during phonological recoding (Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005). Phonological awareness may be more critical in segmenting phonological representations of spelled words.

All of the studies reviewed have centered on the phonological aspect of working memory in early reading skills. A study in 2007 (King, Wood and Faulkner) investigated visual and auditory temporal processing in children aged 4 to 6 divided into two groups. Pre-alphabetic children failed to read any non-words in a test, whereas the alphabetic group demonstrated some skills in reading non-words. The alphabetic group scored higher in reading and spelling, and were faster in reacting to the onset and offset of auditory and visual stimuli. Results indicated that responses to offset visual stimuli are becoming more rapid during the same developmental period when alphabetic ability is beginning to be acquired.

The authors suggested that at the same time children are being introduced to phoneme-grapheme associations, children's sensitivities to visual and auditory stimuli are being more fine-tuned and integrated. Temporal recalibrations may be taking place during the period when children acquire alphabetic and early reading skills. This suggests that growing sensory differentiation is occurring as children progress from understanding language at a syllable level to a more refined phoneme/grapheme level of early reading.

Literature indicates there is not as much empirical evidence for working memory in the role of early reading skills as there is evidence for the relationship between working memory and reading in learning disabilities in older children. Present studies support the idea that the phonological loop, including the phonological store and articulatory rehearsal process, plays an important role in language acquisition, and early reading skills such as phonemic awareness. Phonemic awareness is needed to build on fluency and comprehension skills. Increasing sensory differentiation indicates that visual and auditory channels are becoming more refined. Additional studies have found

evidence that the central executive and episodic buffer also have roles in early reading development in children ages 4 to 6 years.

Working Memory and Early Math Skills

Early Math Skill Development

Gerstan and Chard (1999), along with a number of other researchers, have proposed that early mathematical skill development such as number meaning and number relationships is related to later achievement in mathematics. Children begin acquiring number sense early in life through informal interactions with parents and caregivers. This number sense is critical before preschool, as well as in kindergarten. An operational definition of number sense includes the ability to perceive and interpret small quantities, compare numerical magnitudes, to count and to perform simple arithmetic calculations (Berch, 2005).

Studies have shown that babies can tell objects apart by their shape, size and color within the first six months of life (Bryant, 1992). Wynn (1992) explored whether babies can take in information about the number of objects presented to them by tracking reaction time to changes in the number of objects. Results indicated that infants can discriminate between differences in a small number of items, as well as discriminate numerical equivalence. Researchers have hypothesized if these outcomes indicate the possession of true numerical concepts or merely the result of perceptual discrimination. However, several longitudinal studies have established that the looking time in these experiments using babies' perceptual skills is strongly related to their later IQ (Bryant, 1992). Wynn (1992) has speculated that babies evident numerical capacity "may provide the foundations for the development of future arithmetical knowledge". Babies'

quantitative knowledge is pre-linguistic, as well as primarily perceptual and visual (Resnick, 1989).

Starkey and Cooper (1980) explored a rapid perceptual process called subitizing in two-year old children to distinguish among arrays containing fewer than four items. These researchers presented evidence that 22 month old children can also discriminate exact numbers of items. This raises the possibility that a young child's verbal counting abilities grow in part from the infant's numerical ability.

Preschool children develop a large base of non-numerical quantity knowledge and can use their intuitions to correctly make judgments on non-quantified tasks, which is based on protoquantitative reasoning. Children at this developmental stage express quantity judgments such as big, small, lots and little without using numbers. Such judgments can be thought of as a protoquantitative schema that is perceptual without a specific measurement process. Preschool children begin to use language to label these comparisons. These protoquantitative schemas involving visual and perceptual impressions, paired with later language development, form the basis for later mathematical skills (Resnick, 1989).

The skill of counting is the first step for making preschool quantitative judgments exact. Children as young as 3 and 4 years old begin to develop the knowledge that number names must be matched one-for-one with the objects in a set and that the order of the number names is important, but the order in which the objects are touched is not. After counting is established, a new protoquantitative schema forms when the number-name sequence is integrated with the comparison schema. This can happen as young as 4 years of age and is the basis for the concept of number line. As the preschool child

develops, the earlier schemas of increase/decrease and part-whole also become integrated with counting skill. Resnick (1989) states that when number quantity becomes the dominant way that children think of quantity, they will not be driven by visual-perceptual and linguistic cues.

In the preschool years, counting and knowledge of numerical symbols facilitate the development of number sense. Through counting, children learn important numeracy principles. These principles consist of one-to-one correspondence and the idea that number words should be used in a consistent sequence. The concepts of cardinality and ordinality are additional tenets. Final principles include any set of numbers can be counted and the number of objects is independent of their quality and although one count word should be applied to any given object, the order in which objects are counted is irrelevant. Knowledge of numerical symbols assists in developing number sequencing, one-to-one correspondence and cardinality (Malofeeva, Day, Saco, Young & Ciancio, 2004).

Much literature has been devoted to exploring the failure to understand or perform mathematical skills. The informal protoquantitative schemas play an important role in these cognitive antecedents. If a preschool child has not developed or integrated the schemas, the understanding of how to count objects and the knowledge of number order will be hindered. Also, counting is a backup strategy in the acquisition of arithmetic knowledge which leads to more automatic and accurate fact retrieval (Aunola, Leskinen, Lerkkanen & Nurmi, 2004).

Once children enter school, mathematical growth is not as easy to observe or understand due to formal instruction practices. Most researchers agree that the

development of mathematical skills progresses in a hierarchical manner (Baroody, 1985; Resnick, 1989). Learning basic concepts, skills and the development of number sense provides the basis for mastering more complex skills and concepts. When the ability to retrieve basic number facts becomes automatic, attention resources can be devoted to more complex problem solving (Gersten & Chard, 1999).

Jordon, Kaplan, Locuniak and Ramineni (2007) examined the development of number sense from the beginning of kindergarten through first grade. Number sense performance in kindergarten, as well as number sense growth, was highly correlated with end of first-grade math achievement. Background demographics of income status, gender, age and reading ability did not add explanatory variance over and above the growth of number sense.

More specifically, number sense in kindergarten was explored in regards to later calculation fluency in a study by Locuniak and Jordan (2008). Memory for numbers, number knowledge and number combinations were examined. Number knowledge, which involves magnitude judgments, was uniquely important in developing calculation fluency, but counting skill was not. Results indicated that early number knowledge and number combinations, along with working memory, predicted calculation fluency in second grade. Number sense screening in kindergarten successfully ruled out 84% of children who did not have later calculation fluency difficulties and positively identified 52% of kindergarteners who showed later math fluency difficulties.

Screening early number sense development should be used to identify children with later math difficulties. In addition, the relation of early number sense to later calculation fluency has important implications for math intervention.

Early Math Skills and Working Memory

A 2004 study by Alloway, Gathercole, Willis and Adams examined working memory in the context of nonverbal abilities. Although previous studies have indicated that nonverbal ability is highly correlated with complex memory span measures associated with the central executive, nonverbal abilities are distinct from this construct. According to Baddeley (2003), the capacity to hold and manipulate visuospatial representation provides a measure of nonverbal ability. As the phonological loop plays an important role in language development, it can be assumed that the visuospatial sketchpad may have a role in acquiring semantic knowledge about the appearance of objects and how to use them (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998).

Mathematics skills are divided into two processes of basic arithmetic calculation and mathematic problem solving (Dehn, 2008). Researchers agree that both types of mathematic skills require all components of working memory. Gathercole and Pickering (2000) reported that the combination of visuospatial sketchpad and central executive have the strongest association with calculation abilities. However, Swanson (2006) found that visuospatial sketchpad component of working memory best predicts arithmetic calculation performance and the central executive best predicts mathematics problem solving skills. In regards to children aged 4 to 6 years, Alloway, Gathercole and Pickering (2006) confirmed earlier findings that young children draw more on executive processes than older children when performing visuospatial short-term memory tasks.

Along with Eaglen and Lamont in 2005, the above researchers looked at working memory skills in relation to early learning goals including mathematics. Path analysis indicated that mathematics in young children was uniquely associated with only the

performance on the sentence repetition tasks, which the authors interpreted as tapping the episodic buffer. The authors hypothesized that early math skills such as simple counting, sums and shape comparisons require the integration of learned knowledge, accessed from long-term memory, with current information, and that performance requires the integration of the episodic buffer.

The visuospatial sketchpad's role in early mathematics acquisition appears to change during childhood development. During the preschool years, a child's mathematic skill relies on the visuospatial representations until they develop symbolic and verbal representations of arithmetic concepts (Dehn, 2008). A study by Rasmussen and Bisanz in 2005 explored components of working memory, performance on various arithmetic activities and development in preschool children. They found that visuospatial working memory to be a significant predictor for preschool children in the performance of nonverbal arithmetic problems. Preschool children tend to solve nonverbal problems by using a mental model to represent objects and arithmetic manipulations on these objects.

These researchers also examined inhibition by adding irrelevant information to the problems and discovered this decreases performance because preschool children have difficulty selecting relevant elements and inhibiting responses to irrelevant ones. They hypothesize that the difficulty with inhibition in younger children is due to less involvement of the central executive at this stage of development.

In contrast, Rasmussen and Bisanz found that verbal working memory becomes the best predictor of arithmetic performance by the end of first grade. At this stage, children are more likely to encode and solve problems verbally, using the phonological and central executive components of working memory. In a study using older children,

Swanson and Saches-Lee (2001) found that phonological short-term memory is not as important as other working memory processes, but it does contribute a unique variance in mathematics skills.

On examination of irrelevant problems in first grade children, only a verbally presented measure of the central executive, the backward digit span, related uniquely to performance. Rasmussen and Bisanz (2005) suggested this pattern indicates some fractionation of the central executive for verbal and visual tasks. This was demonstrated previously in adults and older children, not in preschool and early elementary aged children.

Regarding children with arithmetic learning disabilities, Passolunghi (2006) writes that children with poor math ability are not impaired in the phonological loop. Children with poor arithmetic skills demonstrated normal nonword repetition representing phonological working memory, but demonstrated impaired performance on Corsi blocks, indicating impaired spatial working memory.

Baddeley (2003) writes that visuospatial working memory is an active but poorly integrated area of research. Regarding early mathematic skills, the visuospatial sketchpad has been found to be important in predicting arithmetic calculation performance in younger children, with central executive predicting mathematics problem solving skills. The visuospatial sketchpad's role in early mathematics acquisition appears to change during childhood development. Older children are more likely to encode and solve problems verbally, using the phonological and central executive components of working memory when developing mathematic skills.

Linking Developmental Working Memory to School Success

Implications for Learning

The goal of this paper is to present working memory development in relation to child development and early academic skills, therefore some general implications for learning will be discussed. When working memory does not function efficiently in children the learning process is negatively impacted.

Children with working memory difficulties will struggle on simple developmentally appropriate skills, as well as early academic skills. Children with low standardized achievement scores in reading and math usually score poorly on working memory tasks. Learning difficulties in children with below average working memory skills may warrant special education support in schools (Gathercole, Lamont & Alloway, 2006).

Implications for Intervention

Catching working memory difficulties early in childhood is important to early intervention. Such children will fall quickly behind unless remediation strategies are considered (Alloway, 2006). The developmental stage of a child should always be considered in selecting appropriate interventions. The first step in the remediation process is to recognize working memory difficulties in children. Specific verbal or visuospatial processes should be noted. Recall difficulties, failure to follow directions and incomplete tasks can be warning signs.

Evaluate the working memory difficulty in the context of the processing load or activity. Lengthy, unfamiliar and meaningless information can overload taxed memory structures. The amount of information to be remembered should be reduced, along with

simplifying processes and chunking complex tasks into manageable parts. Increasing meaningfulness and generalizing information to previously mastered or familiar information is beneficial (Dehn, 2008).

Important information needs to be repeated, using different modalities, and practiced. The use of memory aids in the form of charts, posters, highlighters and audio recorders should be considered. Visual desk charts for organization are helpful. Personalized dictionaries are beneficial to strengthen verbal skills. Manipulatives such as cubes, counters, abaci, number lines, multiplication grids and calculators are additional memory aids. Finally, helping the child to develop personal, meaningful strategies should occur. Such personal strategies may include a desk card to facilitate a request for help or a window guide for place keeping. Note-taking and organizational strategies should also be taught (Gathercole & Alloway, 2008).

CHAPTER 3

METHODS

This chapter outlines the process in which this study investigates the hypotheses proposed in Chapter One. First, the participants included in this study are described. The measures that operationalize the constructs in the hypotheses are next discussed.

Procedures used during data collection will be explained in detail. Finally, specific data analysis steps will be discussed.

Participants

Students who entered kindergarten ($n = 196$) in two elementary schools for the 2009-2010 school year were sampled for this study. The schools are located in a rural school district, with an overall student population of 6259, thirty miles outside of Pittsburgh, Pennsylvania. The total enrollment for the six elementary schools is 2776, with 1188 students enrolled in the sample schools. The number of students who took the kindergarten screening for the 2009-2010 school year was 461 with a mean number of 60.14. The schools used for the sample had 83 and 98 kindergarten students.

The sample will consist of male and female children ages 4 to 6. Current general demographics for the school district are 96% White, not Hispanic, 2% Black, not Hispanic, <1% Asian, Pacific Islander, <1% Hispanic and <1% Native American Indian/Alaskan, with 18 % children qualifying for free or reduced lunch program. Within the six elementary schools, this number ranges from 14% to 26%. The schools in the sample have a reported 19% and 24% children qualifying for free and reduced lunch, respectively. State demographics are 75% White, not Hispanic, 16% Black, not Hispanic,

3% Asian, Pacific Islander, 7% Hispanic and <1% Native American Indian/Alaskan, with 30% children qualifying for free or reduced lunch program.

Power Analysis

Power analysis determines the probability that the results of a statistical test will lead to rejection of the null hypothesis when it is false. To ensure the most parsimonious statistical approach, a power analysis will be completed to determine adequate sample size. The recommended procedure for statistical analysis referenced in Tabachnick and Fidell (2007) for a medium size relationship between the variables would indicate an alpha level of 0.05, with an effect size of 0.20. For consideration of appropriate sample size with a power of 0.80, G*Power version 3.1.2, a general power analysis program was used (Faul, Erdfelder, Lang & Buchner, 2009). Using the seven predictors in an a priori multiple regression analysis, a sample size of 80 would yield sufficient power, $F(7,72) = 2.14$. For repeated measures, results of this a priori analysis suggests that a minimum sample number of 50, $F(1,2) = 3.09$, would generate sufficient power to generate a moderate effect size of .20 at an alpha level of .05.

Measures

Kindergarten Screening

The kindergarten screening instrument used in this study is the Kindergarten Diagnostic Instrument-Second Edition (KDI-2; Miller, 2000). This instrument is used by the school district primarily to determine need for full day kindergarten. However, the KDI-2 was developed to be a comprehensive screening instrument designed to assess developmental readiness skills in children ages 4 to 6 years. This screening instrument was constructed to identify normal aspects of a child's development while sorting out

potential problems with early intervention and prevention as key (Miller, 2000). The KDI-2 consists of 13 subtests. This instrument was designed to measure the processes behind specific skills than specific skills themselves (Miller, 2000). The subtests include Body Awareness, Concept Mastery, Form/Letter Identification, General Information, Gross Motor, Memory for Sentences, Number Skills, Phonemic Awareness, Verbal Associations, Visual Discrimination, Visual Memory, Visual-Motor Integration and Vocabulary. Raw scores for each subtest and the total instrument are converted into T-scores and percentiles. The KDI-2 can be administered individually or by a screening team.

The KDI-2 was normed on a sample of 893 4-6 year old children drawn from 9 sites across 5 states. The majority of the sample came from the Midwest. Demographics for the sample were 87.9% White, not Hispanic, 1.75% Black, not Hispanic, 1.46% Asian, Pacific Islander, 4.25% Hispanic and 1.75% Native American Indian/Alaskan. Out of the standardization sample, 69% parents reported whether the child had prior preschool experience, with 72.44% of the children reported to have preschool experience.

The KDI-2 is a revision of the KDI. Technical aspects refer to research literature using the KDI. The test-retest reliability of the total KDI score has been evaluated across several studies and ranged from .87 to .91. Concurrent validity for the KDI has been established with several other instruments, positively correlating with the Woodcock-Johnson Revised Tests of Cognitive Ability and Achievement (WJ-R Cognitive Ability score, $r=.80$; WJ-R Skills Achievement Cluster, $r=.77$; WJ-R Broad Knowledge Achievement Cluster, $r=.85$). Concurrent validity was also demonstrated with the Developmental Indicators for the Assessment of Learning-Revised, with a correlation

coefficient of .67, and the Gesell School Readiness Test, with a correlation coefficient of .75. Predictive validity was established using the KDI Total and the Stanford Achievement Test ($r = .74$). Additional studies reported that the KDI Total Score and Factor Scores had adequate reliability for predictive purposes. One study indicated that the KDI verbal and visual-motor readiness skills were significantly related to aptitude, passing proficiency tests, and end-of-the year academic performance.

Studies have examined the KDI subtests in regards to factor structure. A potential three-factor solution was explored which separated the Visual factor into Visual-Motor factor and Visual-Cognitive factor. A two factor structure was found to be most robust. The factor structure of the KDI-2 currently indicates that Memory for Sentences, Verbal Associations, General Information, Concept Mastery, Form/Letter Identification, Number Skills, Phonemic Awareness and Vocabulary load onto the Verbal factor. Cronbach's Alpha for this factor was .93, with the test-retest reliability coefficient being .86. The factor structure of the Nonverbal factor includes Visual-Motor Integration, Body Awareness, Visual Discrimination, Gross Motor and Visual Memory. Cronbach's Alpha for this factor was .80, with the test-retest reliability coefficient being .82. The Cronbach's Alpha for the KDI-2 Total Test score is .93, with the test-retest coefficient of .91. Cronbach's Alpha and test-rest reliability for each KDI-2 subtest can be found in Table 1 (Miller, 2000).

Table 1

Internal Consistency and Test-Retest Reliability for the KDI-2

Subtest	Cronbach's Alpha	Test-Retest Coefficient
Body Awareness	.67	.77
Concept Mastery	.68	.62
Form/Letter Identification	.93	.82
General Information	.67	.62
Gross Motor	.56	.37
Memory for Sentences	.81	.69
Number Skills	.67	.69
Phonemic Awareness	.65	.68
Verbal Associations	.70	.62
Visual Discrimination	.43	.45
Visual Memory	.56	.16
Visual-Motor Integration	.74	.70
Vocabulary	.75	.71
Total Verbal	.93	.86
Total Nonverbal	.80	.82
Total	.93	.91

Working Memory

The relevance of working memory components is dependent on the child's developmental stage. The visuospatial aspect of working memory is correlated with all early skill acquisition. The phonological aspect of working memory is related to early reading skills in children younger than 9 years old. After this age, the central executive plays a greater role in the working memory process and learning (Gathercole, 1998; Swanson & Siegel, 2001). Thus, examination of developmental working memory and

early academic skills in kindergarten aged children should focus on the visuospatial and phonological components of this important neurobiological process.

In this study, kindergarten screening subtests representing the phonological loop and visual-spatial sketchpad were examined in relation to early academic skill probes. Specifically, the Memory for Sentence subtest and Visual Memory subtests from the Kindergarten Diagnostic Instrument, Second Edition (KDI-2; Miller, 2000) were used.

Memory for Sentences was previously called Auditory Memory on the KDI. This subtest is described as measuring verbal auditory short-term memory. The Cronbach's Alpha for the Memory for Sentences Test based upon the standardized sample was .81. The test-retest reliability coefficient was from a 2001 study was .69 (Miller, 2000)

The Visual Memory Test was redesigned on the KDI-2 to tap into a visual memory short-term memory construct. The Cronbach's Alpha for the Memory for Sentences Test based upon the standardized sample was .56. The test-retest reliability coefficient was from a 2001 study was .16. Miller (2000) states that future studies will correlate this test with other known measures of visual-short term memory.

Early Academic Achievement

Early academic achievement in reading and math was measured using the AIMSweb kindergarten curriculum-based measurement probes. The academic skill probes were taken from AIMSweb kindergarten curriculum-based measurement probes for the Test of Early Literacy Measures (TEL) and Test of Early Numeracy Measures (TEN). AIMSweb Benchmark and Progress Monitoring System is a curriculum-based measurement tool used for universal screening, as well as direct, frequent and continuous student assessment of basic skills (Clarke & Shinn, 2002; Shinn & Shinn, 2002). The

TEL is comprised of subtests measuring Letter Naming Fluency, Letter Sound Fluency and Phoneme Segmentation. The TEN includes Number Identification, Quantity Discrimination and Missing Number subtests.

Technical adequacy statistics are not specifically noted for the TEL (Shinn & Shinn, 2002) and attempts to obtain this information from AIMSweb was not successful. According to the National Center on Response to Intervention and Instruction, there is “convincing direct evidence” of the reliability, validity and predictability of the TEL (American Institutes for Research, 2009).

For all subjects, the test-retest reliability on the TEN was examined from the Fall to Winter (13 weeks) and Fall to Spring (26 weeks). All measures were acceptable, approaching or exceeding .80. Inter-scorer reliability for all measures on this early numeracy test was very high, with .99 on Number Identification and Quantity Discrimination, and .98 for the Missing Number measure. Concurrent validity on the TEN has been established with the following criterion measures: Woodcock Johnson Applies Problems subtest, Mathematics Curriculum-Based Measurement (M-CBM) and the Number Knowledge Test. All correlations showed strong evidence of concurrent validity. Correlations with the criterion measures were highest for the Quantity Discrimination measure ranging from .71 to .80, with a median of .75. Number Identification correlations ranged from .60 to .70, with a median of .66. Concurrent validity on the Missing Number measure ranged from .68 to .71 with a median of .71. All Early Numeracy measures have sufficient evidence for good predictive validity. Quantity Discrimination had the highest median correlation of .76, followed by the Missing

Number measure with a median correlation of .72 and Number Identification measure of .68 (Clarke & Shinn, 2002).

Research Design

The design of this study does not involve treatment and progress; instead, it involves the analysis and comparison of existing assessment data. Procedures will involve the review of existing assessment information in each student's file. The data is taken from general education practice where all students are assessed.

This study uses a correlational non-experimental research design, which is concerned with assessing relationships between variables. In this study, the construct of developmental working memory in young children was sampled, with the phonological loop represented by verbal short-term memory, and the visual-spatial sketchpad characterized by visual short-term memory.

Analysis for the first and third research question used the dependent variables of verbal short-term memory and visual short-term memory. Verbal short-term memory was operationalized by a score on the Memory for Sentences Test on the KDI-2. The Visual Memory Test score on the KDI-2 was used to operationalize visual short-term memory (Miller, 2002).

Independent variables were specific early reading and math skills. The early reading skills were operationalized as scores on the AIMSweb curriculum-based measurement probes for Letter Naming Fluency, Letter Sound Fluency and Phoneme Segmentation (Shinn & Shinn, 2002). Early math skills were operationalized as scores on the probes for Number Identification, Quantity Discrimination and Missing Number (Clarke & Shinn, 2002).

Additional variables considered in these analyses were gender, preschool experience and socioeconomic level. Preschool experience was delineated as no preschool experience or prior preschool experience as noted by parents on the kindergarten registration information. Specific preschool program differences regarding length of day and number of days per week were not included in provided information. Socioeconomic level was delineated as those students who meet state criteria for free or reduced lunches or those students who do not meet criteria.

Repeated measures analysis for the second and fourth research question used the dependent variables of verbal short-term memory and visual short-term memory. Verbal short-term memory was operationalized by a score on the Memory for Sentences Tests on the KDI-2. The Visual Memory Test score on the KDI-2 operationalized visual short-term memory (Miller, 2002).

Again, independent variables are specific early reading and math skills. The early reading skills were operationalized as scores on the AIMSweb curriculum-based measurement probes for Letter Naming Fluency, Letter Sound Fluency and Phoneme Segmentation (Shinn & Shinn, 2002). Early math skills were operationalized as scores on the probes for Number Identification, Quantity Discrimination and Missing Number (Clarke & Shinn, 2002). Each of these measures were administered three times through the kindergarten year with Fall, Winter and Spring scores being examined in relationship to the developmental working memory measures. Specifically, Fall AimsWeb measures included Letter Naming Fluency, Number Identification, Quantity Discrimination and Missing Number. Winter and Spring probes were Letter Naming Fluency, Letter Sound

Fluency and Phoneme Segmentation, as well as Number Identification, Quantity Discrimination and Missing Number.

In the final analysis, the independent variables were the verbal and nonverbal factor scores on the KDI-2. These were operationalized as T-scores on these factors. The dependent or grouping variable variables was Tier placement for Response to Intervention and Instruction. This was operationalized as Fall Tier placement as being either Tier I indicating adequate progress or Tier II and Tier III signifying additional interventions were needed to maintain progress.

Procedures

Data was gathered from existing record review files that are part of intact school assessments on each student. Only the necessary information was used. The information was de-identified and entered into a database before any analysis was conducted.

The participants in this study were screened by school district staff in April 2009. Staff members administering the Kindergarten Diagnostic Screening Inventory were trained in using this instrument. Training in specific administration points was updated in March 2009 using the training video viewed by all administrating staff concurrently. Staff members administrating this instrument included intervention coordinators, reading specialists, guidance counselors and physical education teachers. The Memory for Sentences subtest was administered by selected reading specialists at all schools to ensure standardization procedures.

The screening process was conducted in the same manner at all of the six elementary schools and as recommended in the administration manual. The Kindergarten Diagnostic Screening-Second Edition was administered across two days at each school. A

staff member was assigned to a subtest station for each day so that each child was administered the same subtest by the same staff member, and results were tallied. The building secretary entered results into the scoring program. Results of the screening instrument were immediately conferenced with each child's parents. An activity book with recommendations based on the results were highlighted and provided to each family.

When the participants entered school in the fall, AIMSweb academic probes were administered to each child by the intervention coordinators and reading specialists as part of the district Response to Intervention and Instruction initiative. Results of these academic probes are used to design interventions and monitor progress to instruction. In addition to the fall measure, the appropriate AIMSweb academic probes are administered to each student in the winter and spring. These probes are used to determine appropriate interventions in conjunction with the school district's Response to Intervention and Instruction initiative.

Data Analysis

The purpose of this study was to explore empirical evidence linking phonological and visuospatial working memory on kindergarten screening assessments to early reading and math skill performance. The statistical analyses used include descriptive statistics and correlations. Descriptive statistics such as means, standard deviation and frequencies were calculated for demographic data and research variables. Using SPSS 14.0 for Windows (SPSS, Inc., 2005), specific analyses were conducted to address each research question. These analyses include partial correlation analysis, repeated measures and discriminant function analysis. An alpha level of .05 was used to determine statistical significance.

Before the analyses were run, the data were checked for outliers, normality, linearity, homoscedasticity, as well as multicollinearity. The data was examined for normal distribution by looking at univariate and multivariate outliers, as well as skewness and kurtosis. Univariate outliers were considered to be z-scores deviating from ± 4.00 due to the sample of >100 (Mertler & Vannatta, 2005). For multivariate outliers, Mahalanobis distance was evaluated as a Chi-square critical value (Tabachnick & Fidell, 2007). For the df of 21, $p \leq .001$, with critical value = 46.80. Normally distributed data has kurtosis and skew values of zero. One limitation of normality tests is that the larger the sample size, the more likely to get significant results with only slight deviations from normality. Multivariate normality was also considered by examining all of the bivariate scatterplots for elliptical distribution.

Linearity was assessed by using a scatterplot of residuals. Linearity refers to the relationship between two variables fit a straight line. Homoscedasity was also explored because this concept is related to the assumption of normality because if the assumption of multivariate normality is met, the two variables must be homoscedastic (Tabachnick & Fidell, 2007). Pearson's bivariate correlations were run for each of the dependent and independent variables to explore possible significant relationships between variables and to assess for multicollinearity. Additional assumptions for each data analysis will be addressed.

Research Question 1

The first analysis examines the initial research question regarding the relationship between the phonological aspect of the developmental working memory construct and early reading skills measures, taking into consideration gender, prior preschool

experience and socioeconomic status. It is hypothesized that children ages 4 to 6 experiencing difficulty with the phonological aspect of working memory will show early reading skill deficits in the form of phonemic awareness, including letter naming fluency, letter sound fluency, and phoneme segmentation fluency, taking into consideration gender, preschool experience and socioeconomic status variables. Partial correlation analysis was used to explore the relationship between verbal short-term memory using the KDI-2 Memory for Sentences scores and the AIMSweb early reading curriculum-based measurements of Letter Naming Fluency, Letter Sound Fluency, and Phoneme Segmentation. Gender, prior preschool experience and socioeconomic status were used as additional variables.

Research Question 2

The second analysis examined possible interaction between the phonological aspect of the working memory construct and early reading skills measures across time during the kindergarten year. It is hypothesized that there will be an interaction between phonological aspect of working memory and early reading skill measures across time during the kindergarten year. Repeated measures was used to explore a possible interaction between verbal short-term memory using the KDI-2 Memory for Sentences score as the between-subject variable and the Fall, Winter and Spring AIMSweb early reading curriculum-based measurements of Letter Naming Fluency, Letter Sound Fluency, and Phoneme Segmentation as the within-subject variables.

Research Question 3

The third data analysis focused on the relationship between the visual aspect of the developmental working memory and measures of early math skills, taking into

consideration gender, prior preschool experience and socioeconomic status. Children demonstrating visual memory deficits will show weaknesses in early math skills such as acquiring mental representations of objects, number concepts and shapes such as number identification, quantity discrimination and missing number, taking into consideration preschool experience and socioeconomic status. Partial correlation analysis was used to examine the relationship between visual short-term memory using the KDI-2 Visual Memory Test and the AIMSweb early math curriculum-based measurements of Number Identification, Quantity Discrimination and Missing Number. Gender, prior preschool experience and socioeconomic status were considered to be additional variables.

Research Question 4

The fourth analysis examined if there is a possible interaction between the visual aspect of the working memory construct and early math skills measures across time during the kindergarten year. It is hypothesized that there will be an interaction between visual aspect of working memory and early math skill measures across time during the kindergarten year. Repeated measures was used to explore a possible interaction between visual short-term memory using the KDI-2 Visual Memory score as the between-subject variable and the Fall, Winter and Spring AIMSweb Number Identification, Quantity Discrimination, Missing Number as the within-subject variables.

Research Question 5

The final data analysis focused on the research question exploring the relationship between kindergarten screening results and kindergarten progress. It is hypothesized that children demonstrating average performance on specific kindergarten screening instrument subtests, including phonological and visual aspects of developmental working

memory, will demonstrate average progress. KDI-2 Total Verbal and Total Nonverbal composite scores served as the independent variables compared to the Fall Tier placement for Response to Intervention and Instruction as the grouping or dependent variable.

Discriminant analysis was conducted to determine whether the Total Verbal and Total Nonverbal scores on the kindergarten screening inventory would predict Fall Tier placement for the Response to Intervention and Instruction initiative. The Memory for Sentences subtest is included in the Total Verbal, with the Visual Memory subtest being integrated in the Total Nonverbal composite. In this analysis, the purpose is to predict or classify subjects into groups based on a combination of measures.

Fall Tier placement is determined by examining performance on AIMSweb early literacy and numeracy achievement probes. Tier I consists of best practice instruction with universal screening and benchmark assessment for all children throughout the school year. Students scoring below the 25th percentile in 2 of the 3 literacy or numeracy probes are identified as Tier II and are provided targeted interventions in addition to the core instruction to remediate skill deficits. Progress monitoring occurs bi-monthly at Tier II. Deficits below the 10th percentile in 2 out of 3 areas indicate the student is identified as needing more intensive reading and/or math interventions as a Tier III student. Students placed on Tier III are performing significantly below grade level. They continue to receive core instruction with more intensive and frequent reading and/or math instruction, as well as weekly progress monitoring.

CHAPTER 4

RESULTS

The purpose of this study was to explore empirical evidence linking phonological and visuospatial working memory on kindergarten screening assessments to early reading and math skill performance. The results of the data analysis outlined in Chapter Three will be presented in this chapter. Description of demographic and research variables will be offered in context of the study. Preliminary statistical analyses investigate correlations and assumptions as related to the variables, as well as specific analysis. Finally, each research question with statistical results will be summarized.

Descriptive Statistics

The original sample consisted of 196 kindergarten students from two elementary schools. Four cases with outliers were removed using a univariate cut-off z-score of ± 4.00 and multivariate critical value of 46.80 resulting in two cases being deleted from each school. The statistics describing the study sample are presented in Table 2. The remaining sample consisted of 192 kindergarten students with 53.1 % ($n = 102$) of the students coming from one school and 46.9% ($n = 90$) from the other school. In this sample, 56.8% of the students were male ($n = 109$) and 43.2% were female ($n = 83$). The ages of the students ranged from 4 years to 6 years, with 81.8% being age 5 ($n = 157$), 17.2% were 6 years of age ($n = 33$) and 1% were 4 years old ($n = 2$). The mean age was 5.16 years with a standard deviation of .39 year. Students who attended a full day program numbered at 61.5% ($n = 118$), with 38.5% ($n = 74$) of the students attending a half day program. Regarding socioeconomic status, 70.8% of the students did not meet

requirements for a free or reduced lunch (n = 136), with 29.2% meeting guidelines for a free or reduced lunch (n = 56).

Additional demographics include preschool experience and Response to Intervention and Instruction tier placement at the beginning of kindergarten. Regarding preschool experience, 88.0% of the students attended some form of preschool (n = 169) and 12% of the students did not attend preschool (n = 23). Students meeting criteria for universal or Tier I interventions in the fall of the kindergarten year were 84.4% (n = 169). The number of students placed on Tier II were 2.5% (n = 24), with 3.1% (n = 6) students meeting criteria for Tier III interventions. Ethnicity was not reported in the sample data, however, general demographics for the school district are 96% White, not Hispanic, 2% Black, not Hispanic, <1% Asian, Pacific Islander, <1% Hispanic and <1% Native American Indian/Alaskan.

Table 2

Descriptive Statistics of Study Sample (N = 192)

Demographic Variables	Frequency	Percentage
School		
Fort Allen	102	53.1
Stanwood	90	46.9
Sex		
Male	109	56.8
Female	83	43.2
Age		
Age 5	157	81.8
Age 6	33	17.2
Age 4	2	1.0
Program		
Full Day	118	61.5
Half Day	74	38.5
Socioeconomic Status		
Not Free/Reduced Lunch	136	70.8
Free/Reduced Lunch	56	29.2
Preschool Experience		
Preschool	169	88.0
No Preschool	23	12.0
Tier Fall 2010		
Tier I	162	84.4
Tier II	24	12.5
Tier III	6	3.1

Preliminary Statistical Analysis

The sample was examined for any patterns of missing data. Missing data occurred due to students moving in and out of the district in the kindergarten year. Rather than removing all participants with any missing data by using list wise deletion, pair wise deletion was used to result in the maximum possible sample size for each analysis. Using pair wise deletion for analyses, the missing data ranged from 3.6% to 8.9%.

The range, means and standard deviations for the variables are presented in Table 3. The AIMS Web early literacy and numeracy probes were saved as standardized z-scores for comparison. The KDI scores are reported as T-scores. The skewness and kurtosis of each variable distribution are also presented.

Variables with normal distribution include the AIMSWeb literacy probes Letter Naming Fluency Fall, Letter Naming Fluency Winter, Letter Naming Fluency Spring, Letter Sound Fluency Spring, and Phoneme Segmentation Spring. The Kindergarten Screening Inventory variables with normal distribution are Memory for Sentences and Visual Memory, with the Total Verbal, Total Nonverbal and Total variables also following normal distribution, but some deviation at the higher and lower ends.

Phoneme Segmentation Winter, Phoneme Segmentation Spring, Number Identification Fall, Number Identification Winter, Quantity Discrimination Fall, and Quantity Discrimination Spring had high kurtosis values. Number Identification Spring had an extremely high kurtosis value, as well as being negatively skewed. A reason for the extreme distribution of this variable could be due to the majority of children mastering number identification by the Spring of kindergarten year.

Table 3

Descriptive Statistics for Variables

Variable	Range	Mean	SD	Skewness Statistic	Skewness Std. Error	Kurtosis Statistic	Kurtosis Std. Error	N
Early Literacy								
LNF Fall	-1.138 to 2.765	-.016	.948	.560	.179	-.124	.355	185
LNF Winter	-2.469 to 2.972	.001	.964	-.219	.181	.001	.359	181
LSF Winter	-1.654 to 2.656	.001	.988	.632	.181	-.293	.359	181
PSF Winter	-1.730 to 1.935	.011	.999	-.149	.181	-1.111	.359	181
LNF Spring	-2.665 to 2.727	.010	.952	.103	.181	.235	.360	180
LSF Spring	-2.668 to 2.320	.023	.976	-.035	.181	-.196	.360	180
PSF Spring	-3.074 to 2.496	.017	.991	-.576	.181	1.25	.360	180
Early Numeracy								
NI Fall	-1.934 to 1.174	.008	.984	-.511	.180	-1.014	.358	182
QD Fall	-1.148 to 1.582	.006	.992	.102	.180	-1.177	.358	182
MN Fall	-1.080 to 2.236	-.001	.992	.573	.180	-.765	.358	182
NI Winter	-3.483 to .703	.029	.954	-1.548	.181	1.762	.359	181
QD Winter	-2.401 to .920	.017	.986	-.840	.181	-.485	.359	181
MN Winter	-2.036 to 1.418	.005	.986	-.360	.181	-.804	.359	181
NI Spring	-3.406 to .443	.070	.824	-2.653	.181	6.830	.360	180
QD Spring	-3.054 to .586	.004	.900	-1.640	.181	1.734	.360	180
MN Spring	-2.332 to 1.167	.018	.970	-.588	.181	-.574	.360	180
KDI								
Memory for Sentences	18 to 68	47.89	9.659	-.142	.184	-.347	.365	175
Visual Memory	24 to 66	46.84	9.252	-.278	.184	-.603	.365	175
Total Verbal	19 to 71	51.38	10.527	-.597	.184	.101	.365	175
Total Nonverbal	12 to 68	48.16	10.350	-.573	.184	.310	.365	175
Total	21 to 71	50.20	10.399	-.650	.184	-.069	.365	175

Note. LNF = Letter Naming Fluency, LSF = Letter Sound Fluency, PSF = Phoneme Segmentation Fluency,
 NI = Number Identification, QD = Quantity Discrimination, MN = Missing Number

Results of Pearson bivariate correlations between the study variables are reported in Table 4. In the preliminary data analysis, it is important to identify variables with significant relationships, as well as any variables lacking such a relationship. Significant moderate relationships were found on the majority of the variables. Literacy and numeracy probes had some higher correlations between probes measuring different aspects of these skills, but in general were moderately correlated.

Some multicollinearity occurred, as expected, with the composite scores on the Kindergarten Screening Inventory. Total Verbal was highly correlated with the Total score. Total Nonverbal was greater than .80 correlation with the Total (Mertler & Vannatta, 2005). Technically, these variables are more singular than multicollinear as the Total score is a combination of the Total Verbal and Total Nonverbal variables. The Total composite score will not be used in analysis due to high multicollinearity with the Verbal and Nonverbal Total scores.

Research Question 1 Results

The first analysis performed was a partial correlation to explore the relationship between the phonological aspect of the working memory construct and early reading skills measures, taking into consideration gender, prior preschool experience and socioeconomic status. It is hypothesized that children age 4 to 6 experiencing difficulty with the phonological aspect of developmental working memory will show early reading skill deficits in the form of phonemic

Table 4

Correlation Matrix for Variables

Variable	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20
Early Literacy																				
LNF Fall (V1)																				
LNF Winter (V2)	.67**																			
LSF Winter (V3)	.61**	.76**																		
PSF Winter (V4)	.40**	.49**	.57**																	
LNF Spring (V5)	.57**	.70**	.63**	.50**																
LSF Spring (V6)	.36**	.59**	.58**	.42**	.68**															
PSF Spring (V7)	.40**	.34**	.33**	.49**	.41**	.33**														
Early Numeracy																				
NI Fall (V8)	.71**	.69**	.57**	.42**	.54**	.42**	.36**													
QD Fall (V9)	.66**	.56**	.49**	.40**	.47**	.35**	.36**	.77**												
MN Fall (V10)	.60**	.51**	.41**	.32**	.46**	.34**	.34**	.64**	.65**											
NI Winter (V11)	.55**	.65**	.53**	.43**	.59**	.48**	.41**	.73**	.59**	.48**										
QD Winter (V12)	.40**	.55**	.44**	.39**	.46**	.37**	.39**	.66**	.69**	.58**	.71**									
MN Winter (V13)	.51**	.60**	.46**	.36**	.56**	.40**	.32**	.64**	.59**	.69**	.65**	.67**								
NI Spring (V14)	.36**	.44**	.36**	.27**	.54**	.49**	.18**	.46**	.38**	.25**	.63**	.43**	.40**							
QD Spring (V15)	.41**	.44**	.42**	.37**	.46**	.39**	.33**	.53**	.51**	.41**	.56**	.66**	.52**	.46**						
MN Spring (V16)	.47**	.54**	.44**	.32**	.58**	.47**	.29**	.56**	.52**	.60**	.54**	.59**	.70**	.44**	.56**					
KDI																				
Mem. Sentences(V17)	.28**	.19**	.28**	.28**	.28**	.20**	.32**	.24**	.34**	.21**	.31**	.35**	.25**	.16**	.31**	.27**				
Visual Memory (V18)	.33**	.34**	.19**	.16**	.26**	.23**	.23**	.33**	.31**	.33**	.30**	.42**	.26**	.15**	.23**	.23**	.23**			
Total Verbal (V19)	.54**	.42**	.40**	.36**	.40**	.26**	.39**	.53**	.56**	.44**	.49**	.56**	.43**	.32**	.44**	.44**	.78**	.37**		
Total Nonverbal (V20)	.40**	.33**	.33**	.34**	.32**	.27**	.29**	.44**	.37**	.40**	.39**	.51**	.37**	.27**	.40**	.38**	.41**	.53**	.57**	
Total (V21)	.54**	.43**	.41**	.40**	.42**	.30**	.40**	.55**	.54**	.47**	.51**	.60**	.46**	.34**	.48**	.47**	.71**	.47**	.94**	.83**

** Significant at .01

Note. LNF = Letter Naming Fluency, LSF = Letter Sound Fluency, PSF = Phoneme Segmentation Fluency, NI = Number Identification, QD = Quantity Discrimination, MN = Missing Number

awareness, including Letter Naming Fluency, Letter Sound Fluency, Phoneme Segmentation Fluency taking into consideration gender, prior preschool and SES.

Partial correlation is useful in only small models which involve three or four variables so mean values were calculated for the multiple measures of Letter Naming Fluency, Letter Sound Fluency and Phoneme Segmentation Fluency z-scores. This data was examined for normality, linearity and homoscedasticity. Kurtosis and skewness were within acceptable ranges. Examination of the histograms indicated normal distribution. Each of the three Normal Q-Q Plots showed the assumption of linearity was met, with some deviation at the lower and upper ends of each variable. Normal P-Plots of Regression of Standardized Residual and scatter plot were also appropriate. All assumptions were met in the examination of the Memory for Sentences variable.

Results of the partial correlation indicates that there are significant relationships between Letter Naming Fluency, Letter Sound Fluency, Phoneme Segmentation Fluency skills in kindergarten and Memory for Sentence performance on the kindergarten screening measure, KDI-2. There is also a significant relationship with the variable of socioeconomic status. Memory for Sentences scores was lower for children with lower socioeconomic status. When controlling for gender, socioeconomic status and preschool experience, the relationship between Letter Naming Fluency, Letter Sound Fluency, Phoneme Segmentation Fluency and Memory for Sentences slightly decreased.

To further explore specific relationships between the literacy achievement probes and short-term auditory memory as sampled on a kindergarten screening while controlling for gender, socioeconomic status and preschool experience, a semipartial correlation analysis was conducted using a stepwise regression model.

Stepwise regression analysis is exploratory in nature and can determine which specific independent variables make meaningful a contribution to the overall prediction.

Regression results indicate an overall model of three predictors, Letter Naming Fluency, Phoneme Segmentation Fluency and socioeconomic status that significantly predict memory for sentence performance, $R^2 = .173$, $R^2_{adj} = .158$, $F(3,169) = 11.755$, $p < .001$. This model accounts for 17.3 % of variance in Memory for Sentence scores. However, review of the beta weights indicate that that only two variables, Phoneme Segmentation Fluency, $\beta = .318$, $t(169) = 3.625$, $p < .001$, and socioeconomic status, $\beta = -.217$, $t(169) = -2.972$, $p = .003$, significantly contribute to the model. Review of tolerance statistics indicate that all of the independent variables were tolerated in the model.

Because a stepwise approach was used, each step of this model is presented in Table 5. In addition, bivariate and partial correlation coefficients between each predictor variable and the dependent variable are presented in Table 6.

Table 5

Model Summary for Research Question 1

Step	R	R^2	R^2_{adj}	ΔR^2	F_{chg}	df_1	df_2	p
1. LNF	.283	.080	.075	.080	14.910	1	171	.000
2. PSF	.360	.129	.119	.049	9.607	1	170	.002
3. SES	.416	.173	.158	.043	8.834	1	169	.003

Table 6

Coefficients for Final Model for Research Question 1

	B	β	t	p	Bivariate r	Partial r
LNF	.436	.045	.501	.617	.283	.038
PSF	3.072	.318	3.625	.000	.346	.269
SES	-4.601	-.217	-2.972	.003	-.230	-.223

Note. LNF = Letter Naming Fluency, PSF = Phoneme Segmentation Fluency, SES= Socioeconomic Status

Research Question 2 Results

Interaction between the phonological aspect of the working memory construct and early reading skills measures across time during the kindergarten year was the focus of the second analysis in this study. It is hypothesized that there will be an interaction between phonological aspect of working memory and early reading skill measures during the kindergarten year. Repeated measures as a mixed model ANOVA was used to address this research question.

The assumptions of linearity and normality were examined for each of the early literacy variables. Letter Naming Fluency and Letter Sound Fluency were normally distributed with linear Normal Q-Plots. Phoneme Segmentation Fluency had high kurtosis, but generally linear distribution. However, the Winter measure of this variable deviated from linearity at both ends and slightly in the middle. Sphericity varied across the various literacy variables and will be discussed for each set of results. All assumptions were met in the examination of the Memory for Sentences variable.

Examination of the descriptive statistics indicated that the lowest mean scores were found on the fall measures with the highest means on spring achievement probes. There were no significant differences between any of the multiple literacy measures and Memory for Sentences performance. However, there was a main effect of this working memory measure with each of the early reading skill acquisition probes. Interactions varied across the AIMSweb measures throughout the school year and Memory for Sentence performance on the Kindergarten Diagnostic Inventory-Second Edition (KDI-2).

Regarding the repeated measures analysis using Letter Naming Fluency and Memory for Sentences, the Levene's Test was non-significant indicating homogeneity of variance was met. The Mauchly's test revealed the assumption of sphericity was violated with $\chi^2(2) = 9.130, p = .010$. This assumption addresses the relationship between equal variance and assumes the conditions are similar. Violation leads to loss of power and increase Type II error. Therefore, the degrees of freedom were corrected using the Huynh-Feldt estimates of sphericity ($\epsilon = .971$).

Results showed there was no significant difference between Letter Naming Fluency measures throughout the school year and Memory for Sentences, $F(1.94, 326.41) = .094, p = .905$. However, inspection of the between-subjects test indicates a significant main effect of Memory for Sentences on Letter Naming Fluency performance during the Fall, Winter and Spring of kindergarten, $F(1, 168) = 4.447, p = .013$. Results of the Estimated Marginal Means Plot are shown in Figure 1 and indicate an interaction between above average and average Memory for Sentences and Letter Naming Fluency across Fall and Winter measures.

Estimated Marginal Means of Letter Naming Fluency

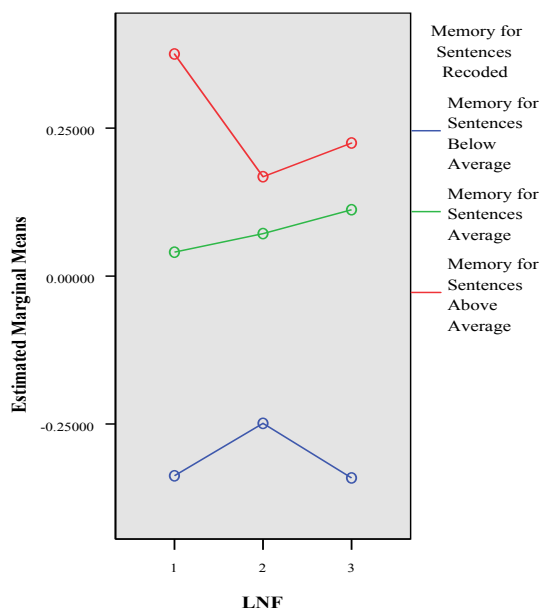


Figure 1. Estimated Marginal Means between Letter Naming Fluency Fall (1), Winter (2) and Spring (3) and Memory for Sentence performance as coded Below Average, Average, and Above Average.

Evaluation of the repeated measures analysis using Letter Sound Fluency and Memory for Sentences indicated the Levene's Test was non-significant indicating homogeneity of variance was met. The Mauchly's test was not applicable as there was an only Winter and Spring measure. Results show there was no significant difference between Letter Sound Fluency measures throughout the school year and Memory for Sentences, $F(1, 170) = .149, p = .700$. Examination of the between-subjects test indicates a significant main effect of Memory for Sentences on Letter Sound Fluency performance during the Fall, Winter and Spring of kindergarten, $F(1, 170) = 3.412,$

$p = .035$. Results of the Estimated Marginal Means Plot are shown in Figure 2 and show an interaction between above average and average Memory for Sentences and Letter Sound Fluency across Fall and Winter measures.

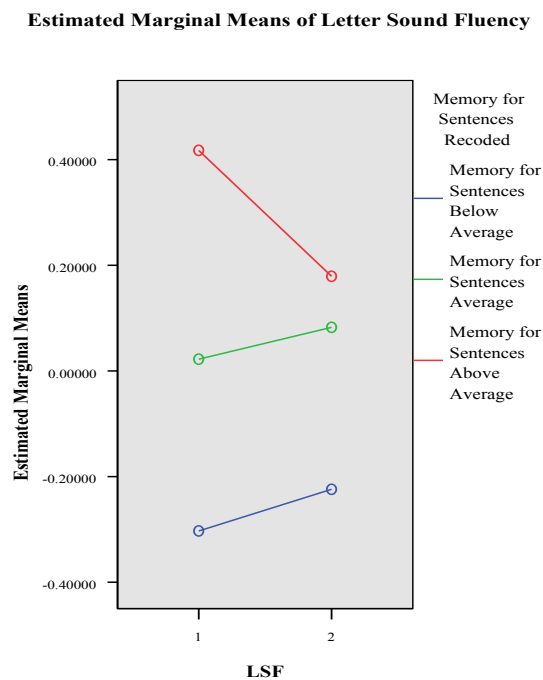


Figure 2. Estimated Marginal Means between Letter Sound Fluency Winter (1), Spring (2) and Memory for Sentence performance as coded Below Average, Average, and Above Average.

On the repeated measures analysis using Phoneme Segmentation Fluency and Memory for Sentences, the Levene's Test was non-significant indicating homogeneity of variance was met. The Mauchly's test was not applicable as there were only Winter and Spring measures. Results showed no significant difference between Phoneme Segmentation Fluency measures throughout the school year and Memory for Sentences,

$F(1, 170) = .197, p = .658$. Inspection of the between-subjects test indicates a significant main effect of Memory for Sentences on Phoneme Segmentation Fluency performance during the Winter and Spring of kindergarten, $F(1, 170) = 10.042, p < .001$. Results of the Estimated Marginal Means Plot are shown in Figure 3. There are no interactions between performance on Memory for Sentences and Phoneme Segmentation Fluency across Winter and Spring measures.

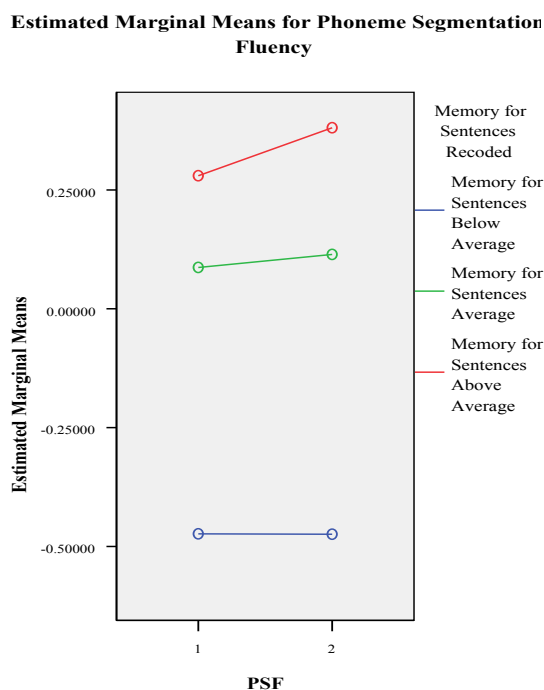


Figure 3. Estimated Marginal Means between Phoneme Segmentation Fluency Winter (1), Spring (2) and Memory for Sentence performance as coded Below Average, Average, and Above Average.

Research Question 3 Results

The third analysis was a partial correlation to explore the relationship between the visual aspect of the developmental working memory and measures of early math skills, taking into consideration gender, prior preschool experience and socioeconomic status. This study hypothesized that children demonstrating visual memory deficits will show weaknesses in early math skills such as acquiring mental representations of objects, number concepts and shapes such as number identification, quantity discrimination and missing number, taking into consideration gender, prior preschool and SES.

Mean values were calculated for the multiple measures of number identification, quantity discrimination and missing number z-scores. The data was examined for normality, linearity and homoscedasticity. Number Identification data was positively skewed and leptokurtic, with generally linear distribution but some deviation. The Quantity Discrimination variable was more normally distributed with slight positive skewness and linear distribution. Inspection of the histogram for the Missing Number data indicated normal distribution and linearity. All assumptions were met in the examination of the Visual Memory variable.

The partial correlation results indicate there is a significant relationship between Number Identification, Quantity Discrimination, Missing Number achievement probes and Visual Memory on the kindergarten screening measure, KDI-2. There is also a significant relationship with the variable of preschool experience in regards to the numeracy probes, but not visual memory. Visual memory was lower for boys, as well as children with lower socioeconomic status. When controlling for gender, socioeconomic status and preschool experience, the relationship between Visual Memory, Number

Identification and Quantity Discrimination increased. The relationship between Visual Memory and Missing Number was unchanged when removing the additional variables of socioeconomic status, gender and preschool experience.

To further explore specific relationships between numeracy achievement probes and short-term visual memory as sampled on a kindergarten screening while controlling for gender, socioeconomic status and preschool experience, a semipartial correlation analysis was conducted using a stepwise regression model. Stepwise regression analysis is exploratory in nature and can determine which specific independent variables make meaningful contribution to the overall prediction.

Regression results indicate an overall model of three predictors, Number Identification, Quantity Discrimination and preschool experience, that significantly predict memory for sentence performance, $R^2 = .184$, $R^2_{adj} = .170$, $F(3,173) = 12.989$, $p < .001$. This model accounts for 18.4 % of variance in visual memory performance. Review of the beta weights indicate that only two variables Quantity Discrimination, $\beta = 3.230$, $t(173) = 2.921$, $p = .004$, and preschool experience, $\beta = 4.825$, $t(173) = 2.315$, $p = .022$, significantly contribute to the model. The tolerance statistics indicate that all of the independent variables were tolerated in the model.

Because a stepwise approach was used, each step of this model is presented in Table 7. In addition, bivariate and partial correlation coefficients between each predictor variable and the dependent variable are presented in Table 8.

Table 7

Model Summary for Research Question 3

Step	R	R^2	R^2_{adj}	ΔR^2	F_{chg}	df_1	df_2	p
1. NI	.353	.125	.120	.125	24.896	1	175	.000
2. QD	.398	.159	.149	.034	7.034	1	174	.009
3. Preschool	.429	.184	.170	.025	5.357	1	173	.022

Table 8

Coefficients for Final Model for Research Question 3

	B	β	t	p	Bivariate r	Partial r
NI	1.113	.120	1.008	.315	.353	.076
QD	3.230	.347	2.921	.004	.394	.217
Preschool	4.825	.167	2.315	.022	.029	.173

Note. NI = Number Identification, QD = Quantity Discrimination, Preschool = Preschool Experience

Research Question 4 Results

Repeated measures as a mixed model ANOVA was used to address the fourth research question involving interaction between the visual aspect of the working memory construct and early math skills measures across time during the kindergarten year. It is hypothesized there will be an interaction between visual aspect of working memory and early math skill measures during the kindergarten year.

The assumptions of linearity and normality were examined for each of the early numeracy variables. Number Identification Fall, Winter and Spring had high kurtosis and negative skew with linearity but deviations throughout the distribution of scores. Quantity Discrimination Fall and Spring also had high kurtosis. The Missing Number variables were normally distributed with linear Normal Q-Plots. Sphericity varied across the various numeracy variables and will be discussed for each set of results. All assumptions were met in the examination of the Visual Memory variable.

Examination of the descriptive statistics indicated that the lowest mean scores were found on the Fall measures with the highest means on Spring probes. There were no significant differences between any of the multiple numeracy measures and Visual Memory performance. However, there was a main effect of this working memory measure with each of the early math skill acquisition probes. Interactions varied across the AIMSweb measures throughout the school year and Visual Memory performance on the KDI.

Regarding the repeated measures analysis using Number Identification and Visual Memory, the Levene's Test was significant indicating homogeneity of variance was not met. The Mauchly's test revealed the assumption of sphericity was violated with $\chi^2(2) =$

36.947, $p < .001$. This assumption addresses the relationship between equal variance and assumes the conditions are similar. Violation leads to loss of power and increase Type II error. Therefore, the degrees of freedom were corrected using the Huynh-Feldt estimates of sphericity ($\epsilon = .854$).

Results showed there was no significant difference between Number Identification measures throughout the school year and Visual Memory, $F(1.71, 293.92) = .115$, $p = .861$. Inspection of the between-subjects test indicates a significant main effect of Visual Memory on Number Identification performance during the Fall, Winter and Spring of kindergarten, $F(1, 172) = 6.158$, $p = .003$. Results of the Estimated Marginal Means Plot are shown in Figure 4 and indicate an interaction between below average, average and above average Visual Memory and Number Identification across Fall, Spring and Winter measures.

Estimated Marginal Means of Number Identification

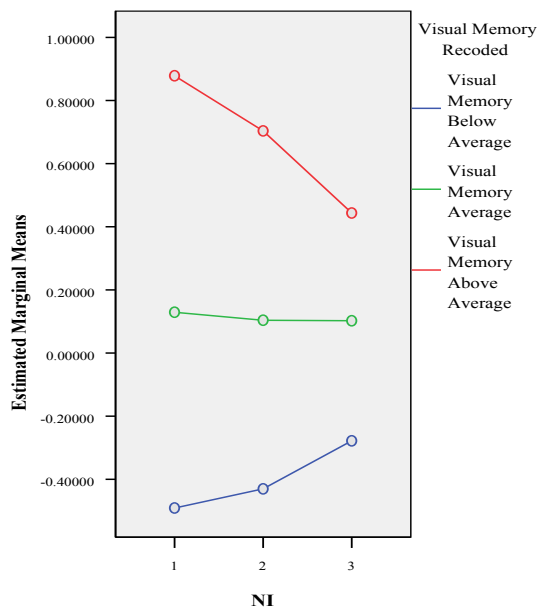


Figure 4. Estimated Marginal Means between Number Identification Fall (1), Winter (2) and Spring (3) and Visual Memory performance as coded Below Average, Average, and Above Average.

Evaluation of the repeated measures analysis using Quantity Discrimination and Visual Memory indicated the Levene's Test was non-significant indicating homogeneity of variance was met for the Fall measure. The Winter and Spring probes did not meet the assumption of homogeneity of variance. The Mauchly's test revealed the assumption of sphericity was violated with $\chi^2(2) = 18.695, p < .001$. The degrees of freedom were corrected using the Huynh-Feldt estimates of sphericity ($\epsilon = .926$).

Results show there was no significant difference between Quantity Discrimination measures throughout the school year and Visual Memory, $F(1.85, 318.51) = .779$,

$p = .451$. Examination of the between-subjects test indicates a significant main effect of Visual Memory on Quantity Discrimination performance during the Fall, Winter and Spring of kindergarten, $F(1, 172) = 10.154, p < .001$. Results of the Estimated Marginal Means Plot are shown in Figure 5 and show an interaction between above average and average Visual Memory and Quantity Discrimination across Fall and Winter measures. There is an interaction between below average, average and above average Visual Memory scores and Quantity Discrimination measures during the Winter and Spring.

Estimated Marginal Means of Quantity Discrimination

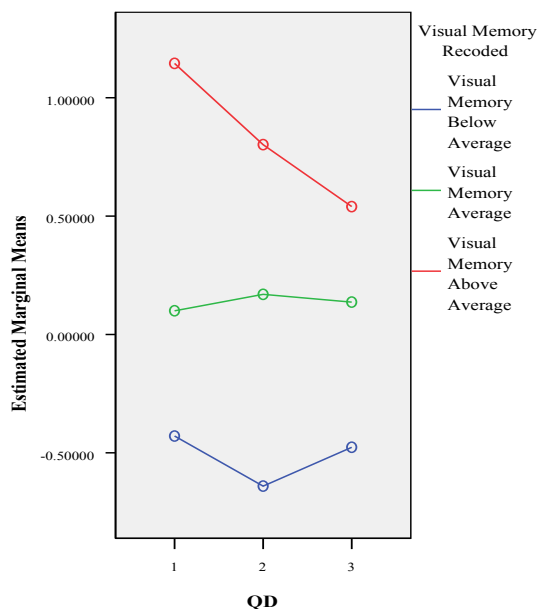


Figure 5. Estimated Marginal Means between Quantity Discrimination Fall (1), Winter (2) and Spring (3) and Visual Memory performance as coded Below Average, Average, and Above Average.

On the repeated measures analysis using Missing Number and Visual Memory, the Levene's Test was non-significant indicating homogeneity of variance was met on the Spring measure. The assumption for homogeneity of variance was not met for the Fall and Winter measures. The Mauchly's test revealed the assumption of sphericity was violated with $\chi^2(2) = 8.490, p = .014$. Huynh-Feldt was used to correct the degrees of freedom for sphericity ($\epsilon = .975$).

Results showed no significant difference between Missing Number measures throughout the school year and Visual Memory, $F(1.95, 335.55) = .092, p = .908$. Inspection of the between-subjects test indicates a significant main effect of Visual Memory on Missing Number performance during the Fall, Winter and Spring of kindergarten, $F(1, 172) = 7.291, p = .001$. Results of the Estimated Marginal Means Plot are shown in Figure 6. There are interactions between performance on above average and average Visual Memory and Missing Number performance across Winter and Spring measures.

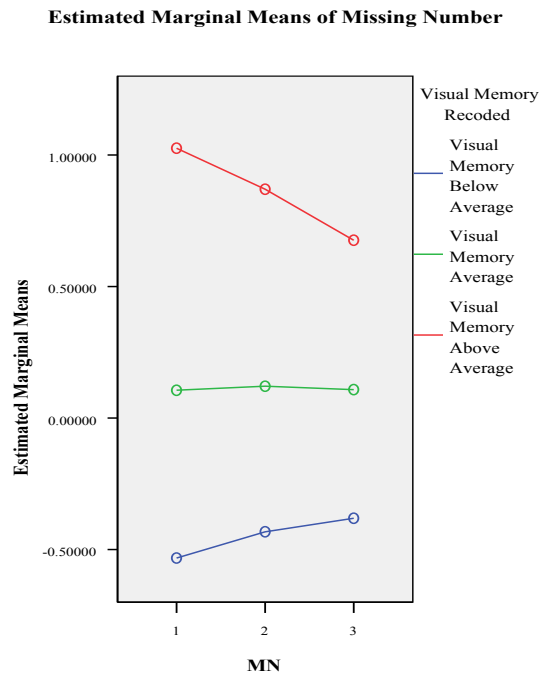


Figure 6. Estimated Marginal Means between Missing Number Fall (1), Winter (2) and Spring (3) and Visual Memory performance as coded Below Average, Average, and Above Average.

Research Question 5 Results

For the final research question, discriminant analysis was used to explore the relationship between kindergarten screening skills and early academic progress, taking into consideration Response to Intervention and Instruction (RtII) Tier placement for Fall. It is hypothesized that children who demonstrate average performance on specific kindergarten screening instrument composite scores, including phonological and visual aspects of developmental working memory, will demonstrate average progress on early academic skill probes and be placed on Tier I for universal interventions.

Examination of assumptions indicates that linearity and normality are met. Outliers were removed prior to any analysis. Results of Box's M test is significant suggesting that homogeneity of covariances can be assumed. There was no evidence of multicollinearity between the variables. Descriptive group statistics show that Tier I had the highest means on Total Verbal and Total Nonverbal, with the means for Tier II being lower and the Tier III means being lowest.

The ANOVA was the overall test of how the model differentiates discriminant scores better than chance. Results indicated significant results for both predictor variables with Total Verbal being $F(2,172) = 51.895, p < .001$ and Total Nonverbal being $F(2,172) = 33.690, p < .001$. The analysis generated two functions, however, only function one was significant, $\Lambda = .572, \chi^2(4, N=175) = 95.824, p < .001$, with 9.8% of the function variability explained by Tier placement. Both variables were entered into the function. Table 9 shows the standardized function coefficients and correlation coefficients. Classification results revealed that the original grouped cases were classified with 90.9% accuracy. Accuracy for each group was 96.6% for Tier I, 59.1% for Tier II and 60.0% for Tier III. Cross-validation results supported the original accuracy levels with 90.3% correctly classified overall.

Group means for the function indicated that students placed on Tier I had a function mean of .354, those on Tier II had a function mean of -1.747 and those students placed on Tier III had a function mean of -2.801. This suggests that kindergarten students who were placed on Tier I had the highest mean score and Tier III had lowest mean scores on Total Verbal and Total Nonverbal screening inventory results. Figure 10 shows the Canonical Discriminant Functions.

Table 9

Correlation Coefficients and Standardized Function Coefficients

	Correlation Coefficients with Discriminant Function	Standardized Function Coefficients
Total Verbal	.910	.740
Total Nonverbal	.729	.448

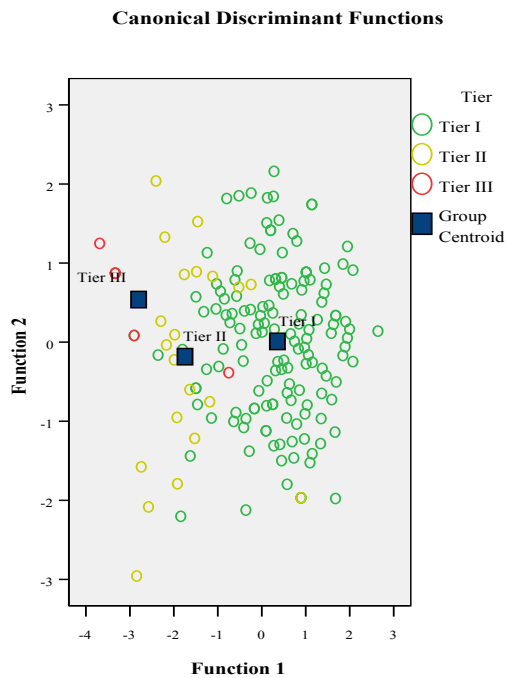


Figure 7. Canonical Discriminant Functions for Fall Tier placement predicted from Total Verbal and Total Nonverbal kindergarten screening scores.

CHAPTER 5

DISCUSSION

Brain-based initiatives in education have prompted researchers to examine the biological mechanisms associated with learning in the hope that understanding and empirical evidence can maximize learning potential. (Alloway, Gathercole, Adams, Willis & Lamont, 2005; Alloway, Gathercole, Willis, & Adams, 2004; Gathercole & Alloway, 2006). In addition, school readiness mandates require that children be screened as they enter school in order to provide information about where the child's developmental path may be off track and used to design interventions to address these areas (Blair, Knipe, Cummings, Baker, Gamson, Eslinger & Thorne, 2007; Brassard & Boehm, 2007; Mehaffe & McCall, 2002; Swanson & Siegel, 2001).

Much research has currently centered on the hypothesis that working memory skills and development are the foundation of individual differences in learning ability (Alloway, Gathercole, Willis & Adams, 2004; Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005; Alloway, Gathercole, Adams & Willis, 2005; Baddeley, Gathercole & Papagno, 1998; Swanson & Saches-Lee, 2001; Swanson & Jerman, 2007). The relevance of working memory components is dependent on the child's developmental stage. The visuospatial aspect of working memory is correlated with all early skill acquisition with specific predictability for nonverbal arithmetic problems in preschool children (Rasmussen & Bisanz, 2005; Swanson, 2006). The phonological aspect of working memory is related to early reading skills in children younger than 9 years old. (Gathercole, 1998; Swanson & Siegel, 2001).

Examination of developmental working memory and early academic skills in kindergarten aged children should focus on the visuospatial and phonological components of this important neurobiological process. A deficit in either of these areas could impact early learning, as well as further development of working memory (Baddeley, Gathercole & Papagno, 1998; Gathercole, 1998; Gathercole & Alloway, 2008).

This study served to explore the hypothesis that kindergarten readiness screening results could be examined for working memory strengths and weaknesses with possible links to readiness skill performance. Understanding specific working memory processes in the development of early reading and math skills could provide a framework for structuring interventions as a child enters school in order to maximize the learning process.

In Chapter Five, significant research results will be summarized as related to the study's hypotheses, as well as conjunction with current literature. Study limitations, implications for future research and overall conclusions will also be discussed.

Summary

The first research question focused on the relationship between the phonological aspect of the working memory construct and early reading skills measures, taking into consideration gender, prior preschool experience and socioeconomic status. It was hypothesized that children ages 4 to 6 experiencing difficulty with the phonological aspect of developmental working memory will show early reading skill deficits in the form of phonemic awareness, including letter naming fluency, letter sound fluency,

phoneme segmentation fluency with gender, prior preschool experience and socioeconomic status as additional variables.

Results of this study supported that there are significant relationships between letter naming fluency, letter sound fluency, phoneme segmentation and memory for sentence performance on a kindergarten screening inventory. There was also a significant relationship with socioeconomic status, with gender and preschool experience not significant. Specifically, a model of letter naming fluency, phoneme segmentation and socioeconomic status predicted performance on a memory for sentence task, with the best predictors being phoneme segmentation fluency and socioeconomic condition. Lower socioeconomic status was associated with lower memory for sentence performance. Studies show that poverty experienced in early childhood hinders the development of school readiness skills (McLoyd, 1998). There was no relationship with gender and preschool experience.

Research Question Two also examined early literacy skills in kindergarten and short-term auditory memory skills as sampled on a kindergarten screening measures. This question concentrated on the interaction between the phonological aspect of the working memory construct and early reading skills measures across time during the kindergarten year. It was hypothesized there will be an interaction between phonological aspect of working memory and early reading skill measures during kindergarten. Results showed no significant differences between any of the early literacy measures in the Fall, Winter, and Spring of the kindergarten year with memory for sentence performance. However, there was a main effect of this working memory measure with letter naming fluency, letter sound fluency and phoneme segmentation performance. Higher

performance on the short-term auditory memory task, memory for sentences, resulted in higher literacy skill probe scores.

Interactions varied across the early literacy measures throughout the school year and memory for sentence performance on kindergarten screening results. There were interactions between above average and average performance on letter naming fluency and letter sound fluency with memory for sentence performance. A possible reason for the interaction could be the variable of socioeconomic status. Children with higher socioeconomic status often are exposed to more enriching experiences. These children may score higher on the memory for sentences kindergarten screening subtest, as well as initially demonstrate more knowledge of letter names and sounds due to educational opportunities. They continue to score above the children in the average range, but as the newly presented knowledge demand increases, their rate of acquisition is only slightly higher than that of the other children.

There was no interaction with below average performance on early literacy measures and memory for sentence performance, but there was a spike in scores on the winter measure on letter naming fluency with a decrease in the spring measure. A possible reason for this could be due to interventions provided from fall to winter due to Tier II or III placement on the Response to Intervention and Instruction model. Upon improvement on the winter measure, these children no longer meet criteria for more intensive Tier interventions and this additional instruction ceases. However, due to continued below average memory for sentence performance, they will not make the gains of students with average to above average short-term auditory memory. This builds a case

for using the results of kindergarten screening developmental working memory measures to inform intensity and continuity of interventions despite increasing skill probe scores.

The focus of Research Question Three was the relationship between the visual aspect of the developmental working memory and measures of early math skills, taking into consideration gender, prior preschool experience and socioeconomic status. This hypothesis suggested children demonstrating visual memory deficits will show weaknesses in early math skills such as acquiring mental representations of objects, number concepts and shapes such as number identification, quantity discrimination and missing number, with gender, prior preschool and SES as additional factors.

Results of this study supported that there are significant relationships between number identification, quantity discrimination and missing number skills and visual memory performance on a kindergarten screening inventory. There was also a significant relationship with preschool experience, with gender and socioeconomic status being not significant. A model of number identification, quantity discrimination, missing number skills and preschool experience predicted performance on a visual memory task, with the best predictors being quantity discrimination and preschool experience. Visual memory performance was lower for boys, as well as children with lower socioeconomic status.

Early numeracy skills and visual short-term memory as sampled on a kindergarten screening were examined in Research Question Four. This question focused on the interaction between the visual aspect of the working memory construct and early math skills measures across time during the kindergarten year. It was hypothesized there will be an interaction between visual aspect of working memory and early math skill measures during the kindergarten year.

Results showed no significant differences between any of the early numeracy measures in the Fall, Winter, and Spring of the kindergarten year with visual memory performance. There was a main effect of this working memory measure with number identification, quantity discrimination, and missing number skills. Higher performance on the short-term visual memory task resulted in higher numeracy skill probe scores.

Interactions varied across the early numeracy measures throughout the school year and visual memory performance on kindergarten screening results. There were interactions between performance levels on number identification, quantity discrimination and visual memory performance. A possible reason for the interaction could be the variable of preschool experience. Children with preschool experience would have been exposed to basic readiness skills such as number identification and quantity. These children may score higher on the visual memory kindergarten screening subtest, as well as initially demonstrate more number knowledge due to educational opportunities. They continue to score above the children in the below average range, but as the newly presented knowledge demand increases, their rate of acquisition is only slightly higher than that of the other children. In addition, ceiling scores on these specific probes do not go beyond mere number naming.

The final research question addressed the relationship between kindergarten screening skills and early academic progress, taking into consideration RtII Tier placement for Fall. This hypothesis proposes that children who demonstrate average performance on specific kindergarten screening instrument subtests, including phonological and visual aspects of developmental working memory, will demonstrate

average progress on early academic skill probes and be placed on Tier I for universal interventions.

Results indicated that kindergarten screening measures of nonverbal and verbal skills, including short-term auditory and visual memory, successfully predict Response to Intervention and Instruction Tier placement in the Fall semester. Using early literacy and numeracy achievement probes, kindergarten students who were placed on Tier I demonstrated average performance on nonverbal and verbal composites on a kindergarten screening inventory. Students with lower achievement composite scores met criteria for Tier II or Tier III interventions. These findings suggest that interventions should be implemented as soon as a child enters school in order to maximize progress.

Limitations

The purpose of this study was to explore the relationship between kindergarten readiness screening results involving developmental working memory and readiness skill performance. Despite significant results, there are several limitations. The overall test-reliability of the verbal and nonverbal kindergarten screening composites, as well as the memory for sentences subtest, were satisfactory. However, the visual memory subtest Cronbach's Alpha was only .53. This diminishes the possibility that similar results may be obtained using the same test under similar conditions.

Generalizability of the results is another concern. Although the sample size was sufficient and was obtained from two different schools with various socioeconomic conditions, the demographics are still higher than that of the state representation. Ethnicity was also more homogeneous than the overall ethnicity of the state. A more heterogeneous sample may produce varying results.

The extent of preschool experience was not specified. Some students attended whole day kindergarten programs, some attended only day care with minimal instruction and some attended a district-run half-day program used to provide child development training at the high school. It is more than likely that preschool experience varied greatly across the sample. In addition, there were approximately 30 children who received early intervention services, but this varied from only speech and language support, to inclusion programs with itinerant support to full day center programming. There was no way to track which students received these services or if the kindergarten screening instrument was administered to all or any of these early intervention students. Often, children with significant delays or behavioral concerns do not participate in kindergarten screening because they have been evaluated through the early intervention transition to school-age process.

Another limitation of this study was that examination of missing data seemed to suggest that subjects with lower socioeconomic status had more missing data indicating that they moved in and out of the district. Thus, the final analysis may have not included this data due to missing scores. Finally, there was varying instruction presented due to half day and full day kindergarten programs. 61% of the students received full day instruction, with only 74% attending half-day programs. One caveat for this limitation is that children with the lowest scores on the kindergarten screening results were automatically included in full day kindergarten classrooms, unless parents opted for a half-day program.

Conclusions

Working memory and early reading skills

There is considerable evidence that the phonological loop has an effect on long-term phonological learning. Baddeley (2003) states that the phonological loop should facilitate language acquisition by storing temporary representation for new phoneme sequences and the articulatory system should facilitate learning through rehearsal. This short-term processing component of verbal information is needed for language acquisition which is the foundation of reading development.

Phonological short-term memory may influence learning letter-sound correspondences and storing generated phonological sequences prior to blending and output during phonological recoding (Alloway, Gathercole, Adams, Willis, Eaglen & Lamont, 2005). In a study of working memory and phonological awareness as predictors of progress for early learning skills, Alloway, Gathercole, Adams, Willis, Eaglen & Lamont (2005) found that capacity to store and process information over short periods of time and the awareness of phonological structure may play a critical part in the early learning for children. A review of literature indicates the statistical relationship between phonemic awareness skills and beginning reading success is robust (Ball & Blachman, 1991). Phonemic awareness is necessary when learning to decode, or use letter-sound relationships to read unfamiliar words, and is highly dependent on spoken language awareness. (Spear-Swerling, 2007).

Findings from this study support this relationship. The correlation of phonemic segmentation skills in kindergarten and short-term auditory memory performance on a kindergarten screening measure is predictable. Despite the effect of socioeconomic

status, lower short-term auditory memory performance was associated with lower letter naming fluency, letter sound fluency and phoneme segmentation skills throughout the kindergarten year. Thus, more intensive literacy skill reinforcement, as well as short-term auditory memory interventions, should be presented as soon as at-risk children enter school.

Working memory and early math skills

According to Baddeley (2003), the capacity to hold and manipulate visuospatial representation provides a measure of nonverbal ability. As the phonological loop plays an important role in language development, it can be assumed that the visuospatial sketchpad may have a role in acquiring semantic knowledge about the appearance of objects and how to use them (Baddeley, 2003; Baddeley, Gathercole & Papagno, 1998).

Regarding early mathematic skills, the visuospatial sketchpad has been found to be important in predicting arithmetic calculation performance in younger children, with central executive predicting mathematics problem solving skills (Rasmussen & Bisanz, 2005). Researchers have found visuospatial working memory to be a significant predictor for preschool children in the performance of nonverbal arithmetic problems (Rasmussen & Bisanz, 2005; Swanson, 2006). Preschool children tend to solve nonverbal problems by using a mental model to represent objects and arithmetic manipulations on these objects (Rasmussen & Bisanz, 2005). The visuospatial sketchpad's role in early mathematics acquisition appears to change during childhood development. Visual-spatial abilities are more important for early number skill acquisition in preschool children.

The results of this study support this theory. The relationship of early numeracy skills in kindergarten and short-term visual memory performance on a kindergarten

screening measure is predictable. Although preschool experience has an effect on early numeracy skills, short-term visual memory performance was associated with lower number identification quantity discrimination and missing number achievement. More intensive numeracy skill instruction, as well as short-term visual memory interventions, should be presented as soon as at-risk children enter school.

Kindergarten screening results as a predictor of early academic skills

Research indicates there is evidence linking working memory functions such as the phonological loop, including the phonological store and articulatory rehearsal process to language acquisition and early reading skills. The visuospatial sketchpad has been linked to arithmetic calculation in early childhood, with central executive predicting mathematics problem solving skills.

Understanding working memory and academic abilities are important to designing appropriate interventions. If a child enters school with a delay or deficit in working memory, vital early skill attainment may be hindered (Blair, Knipe, Cummings, Baker, Gamson, Eslinger & Thorne, 2007; Dehn, 2008).

Findings from this study show that children's performance on a composite verbal and nonverbal screening inventory predicts Response to Intervention and Instruction Tier placement in the Fall. There is an emerging foundation of empirical evidence that suggests more intensive interventions at the kindergarten level, as well as longitudinal intervention may be beneficial to all children (Gersten & Chard, 1999).

Empirical evidence linking phonological and visuospatial working memory on kindergarten screening assessments to early reading and math skill performance can provide an initial starting point for intervention as a child enters school, rather than

waiting for later kindergarten curriculum based assessment result. In addition, such empirical evidence may provide educators with awareness of individual early working memory aspects in order to provide direct teaching of rehearsal strategies, mnemonics and other working memory strategies to improve efficiency and maximize future learning.

Implications for Practice

The results of this study have implications for specific learning disability criteria as outlined in changes to the Individuals with Disabilities Improvement Act (IDEIA) of 2004, as well as practice in the schools. Changes made to the Individuals with Disabilities Education Act in 2004 include Response to Intervention and Instruction (RtII) as a reaction to the ability-achievement discrepancy model. RtII methods advocate for research-based instruction, regular progress monitoring, and empirical decision making in the context of both standardized and problem solving protocols (Hale, 2006).

The Individuals with Disabilities Education Improvement Act of 2004 (IDEIA) also includes consideration of a pattern of strengths and weaknesses in performance, achievement or both relative to age, standards or intellectual development. Districts may adopt an RtII approach or consider a pattern of strengths and weaknesses. Hale, Kaufman, Naglieri and Kavale (2006) support the use of both methods in determining a specific learning disability. There are various models used to operationalize a Pattern of Strengths and Weaknesses model. Naglieri, Hale and Fiorello, Flanigan, Ortiz and Alfonso, and Berninger outline models in which standardized cognitive, neurological and achievement assessments are used to determine processing strengths and weaknesses in a student's profile (Hanson, Sharman & Esparza-Brown, 2009). The common thread

running throughout these Processing Strengths and Weaknesses models are inherent processing abilities. Torgesen (2002) refers to these processing skills as intrinsic. He cites the definition of process as “a set of steps, operations, or developing conditions that follow one another in a certain way and that lead to, or produce, a given outcome.” Intrinsic refers to the basic information processing limitations that can cause a child to have difficulty learning specific skills. These intrinsic processing limitations may be the result of neurological or environmental conditions.

The identification of a specific learning disability requires the investigation of these inherent processing strengths and weakness in regards to the difficulty of academic skills development. Results of this study indicate that children with deficits in auditory and visual memory have difficulty acquiring foundations of early reading and math skills. This difficulty persists across the kindergarten year and is associated with Tier II or Tier III placement in the Response to Intervention and Instruction process. Thus, kindergarten aged children exhibiting auditory or visual memory difficulties will require more intensive interventions in regards to the acquisition of early academic skills. However, difficulty with early literacy and numeracy skills are symptoms of the underlying processing weaknesses.

This leads to the implications of the current study in regards to practice in the schools. Results show, in addition to specific risk factors, children enter school with specific processing weaknesses concerning developmental working memory aspects. These deficits are intrinsic as defined by Torgesen (2002). Interventions and instruction should be tailored to the specific deficits in order to maximize learning. That is not to say that identification of a specific learning disability is inevitable. Instead, the results of this

study should serve to inform the educational program. Children entering school with developmental working memory deficits should be provided interventions that teach strategies in order to strengthen processing skill weaknesses. More intensive, frequent reading and math instruction will not address these specific weaknesses. Strategies, skills and practice in auditory and visual memory performance are needed to address the processing difficulty before academic proficiency is hindered.

Recommendations for Future Research

This study was an attempt to fill a gap in empirical evidence linking kindergarten screening using developmental working memory measures with early skill acquisition. Dehn (2008) recommends that more age-appropriate early childhood short-term and working memory measures are needed to screen preschoolers at risk for language and literacy difficulties. Additional kindergarten screening instruments that sample more specific working memory processes in preschool children should be developed. The role of verbal memory in early literacy and numeracy changes as children progress through school (Ramussen & Bisanz, 2005). The visuospatial aspects of working memory are correlated with all early skill acquisition (Gathercole, 1998; Swanson & Siegel, 2001). Exploration of phonological and visuospatial function with additional measures of the central executive may yield a more specific view of the role of working memory in early academic skills development.

There is much literature regarding assessment of working memory components and specific skill acquisition across various ages of childhood. This study has contributed a bit more information in this area. More specific empirical evidence is needed to support

the application of neuroscience principles to school readiness practices, specifically in regards to screening assessments, working memory and early academic performance.

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APPENDIX



DUQUESNE UNIVERSITY

INSTITUTIONAL REVIEW BOARD

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Dr. Paul Richer
Chair, Institutional Review Board
Human Protections Administrator
Phone (412) 396-6326 Fax (412) 396-5176
e-mail: richer@duq.edu

June 25, 2010

Dr. Jeff Miller
School of Education
Duquesne University
Pittsburgh PA 15282

Re: Linking developmental working memory with early academic skills
(Protocol # 10-65)

Dear Dr. Miller:

Thank you for submitting the research protocol from your student, Ms. Janice Decker, to the IRB.

Based on the review of Dr. Sarah Peterson, IRB Representative, and my own review, your study is approved as Exempt based on 45-Code of Federal Regulations-46.101.b.4, regarding data without identifiers extracted records existing at this time.

This exempt approval pertains strictly to the research described in the protocol. If you and Ms. Decker intend to make a change in the research, you must re-submit an amended proposal before proceeding. In addition, you should inform the IRB if any adverse events or procedural problems occur impacting subjects. In correspondence about the research, please refer to the protocol number shown after the title above.

Once the study is complete, provide our office with a short summary (one page) of your results for our records.

Thank you for contributing to Duquesne's research endeavors.

Sincerely yours,

A handwritten signature in dark ink, appearing to read "Paul Richer". The signature is fluid and cursive, with a small dot at the end.

Paul Richer, Ph.D.

C:
Ms. Janice Decker
Dr. Sarah Peterson
IRB Records